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Vol. 248 JULY, 1949 No. 1

HISTORY OF POWER TRANSMISSION

BY

W. A. WILLIAMS[1]

INTRODUCTION

There has been an over-abundance of vagueness and considerable misconception surrounding the actual origin of the elements of Power Transmission in use today. For instance, it is a popular belief that the flat belt and pulley combination is as old as the ages, and that such means of power transmission were used by the Egyptians, Babylonians and other early civilizations. A careful study of the available literature shows that the toothed gear was the earliest form of mechanical power transmission in use for the transmission of continuous motion, and that pulleys and belts did not come into use for many centuries after the development of gears.

In the pre-Christian era, toothed wheels were in use as early as 330 B.C., according to the writings of the philosopher Aristotle, in which toothed wheels are mentioned for use in windlasses. By 250 B.C. toothed wheels were in use in hydraulic organs and clocks. About this time an advanced form of toothed wheel was the lantern pinion consisting of two disks with bars connecting them at their peripheries; the bars forming the teeth which engaged projecting pins on a gear wheel usually ran on an axis 90° from the axis of the lantern pinion. This construction is illustrated in Fig. 1 on a set of gears used to drive a stone mill in Rome some time prior to 16 B.C.

All of the evidence points to the fact that power was first applied to the grinding of wheat and other grains, and that power was seldom used for any other purpose until more than 1000 years later. Several forms of water-driven mills have been recorded. The earliest form did not have gears, but utilized a water wheel that revolved on a vertical

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(Note—The Franklin Institute is not responsible for the statements and opinions advanced by contributors in the JOURNAL.)

axis and connected directly to the mill stone. Figure 1 is taken from the writings of Vitruvius which appeared about 16 B.C. The actual origin of the construction may have been much earlier because Vitruvius was not claiming originality for the constructions shown in his writings but was simply showing what was in use in his day.

Another interesting illustration from Vitruvius but which also appears in the works of Hero of Alexandria about 100 years earlier is shown in Fig. 2, which shows a very ingenious set of worm drives which operated from the axle of a stagecoach or wagon as a means of recording the distance traveled. The device was geared so that a day's journey

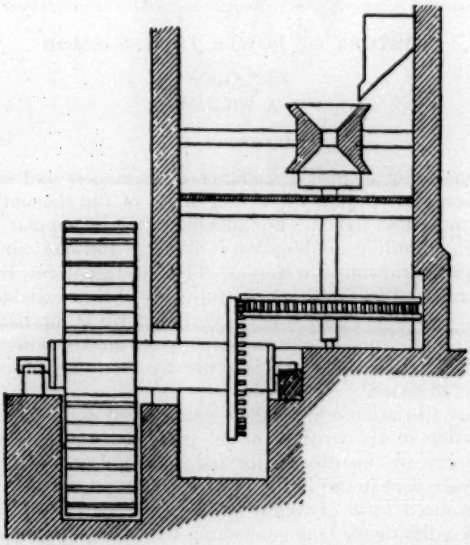

FIG. 1.

usually resulted in one complete revolution of the indicating hand on the dial at the top of the instrument.

The predecessor of the modern bucket elevator was the chain-of-pots well pump which had its origin either in the Far East or in Egypt, and was operated either by animal power through wooden gears similar to those shown in the mill in Fig. 1, or by means of the rope drive shown in Fig. 3. An interesting aspect of the illustration in Fig. 3 is that the rope drive apparently does not provide for continuous motion and yet the chain-of-pots is constructed so that it could rotate continuously. It is a matter of speculation as to whether the illustrator failed to

understand that the drive was intended to provide for continuous motion or whether the art had actually not progressed to that degree when this drawing was made. This picture was taken from Usher, "History of Mechanical Inventions."

There is very little evidence of advancement in mechanical power transmission after the fall of the Roman Empire. About the only major development was the use of windmills for grinding grain following the Crusades. The evidence indicates that the Crusaders brought back the designs of windmills from the East around 1200 A.D., and

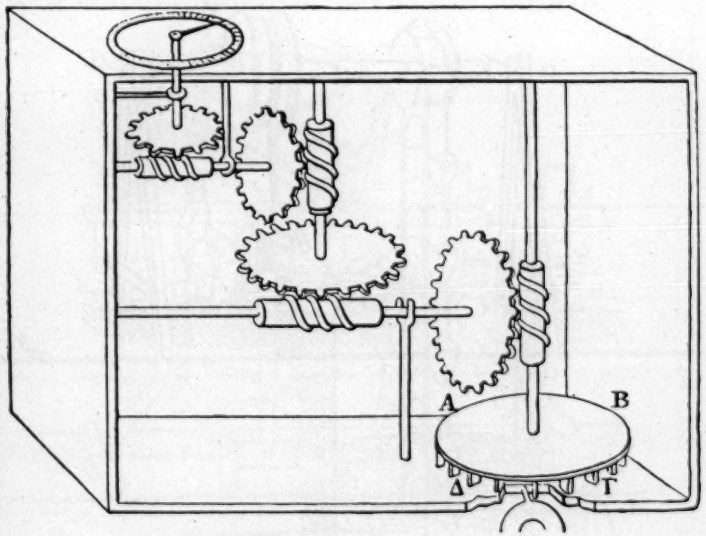

FIG. 2.

that the mills found ready acceptance in areas where water power was not available. Windmills were not used for anything but milling until several hundred years later. Incidentally, the term "millwright" was applied to the early specialists who constructed and maintained both water-powered and wind-powered mills.

The earliest recorded use of continuous power transmission by a cord travelling over two pulleys was on a quilling wheel for winding thread on a bobbin. This development took place around 1200 A.D. The early American and European spinning wheels took their basic construction from these quilling wheels and drill spindles. The earliest evidence of the use of water power for purposes other than

milling is the illustration shown in Fig. 4 of a sawmill erected sometime in the 14th century in Germany. The drawing is interesting because it not only shows the crudeness of their mechanical construction but also the roughness of their draftsmanship. It takes a considerable amount of imagination to figure out how this sawmill worked, but there is sufficient evidence in this illustration to indicate that it did work.

During the Renaissance period, from 1400 A.D. to 1600 A.D., great strides were made in the use of power and mechanical contrivances for the manufacture of implements, clothing and building materials.

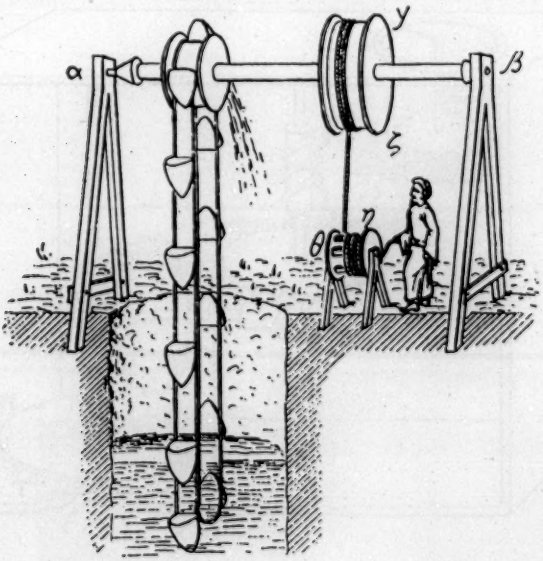

FIG. 3.

The incomparable Leonardo Da Vinci is credited with a long list of inventions among which are the flat belt and crossed belt, spiral gears, linked chain, the flyer for continuous spinning of silk and other fibers, and antifriction bearing. Leonardo was so productive that many of his inventions did not see daylight for from 100 to 200 years after his death when his notes were used by subsequent enterprisers to further their own gains. Many inventions, which were for a long time credited to others, have since been found in the notes left by Leonardo.

In the search for illustrative material on this subject, a veritable gold mine was found in Diderot's *Encyclopédie*, which was published in

1778 in France under the auspices of Catherine the Great of Russia. This encyclopedia describes in detail all of the mechanical arts of the period. It does not designate the date of origin of each of the machines and processes shown, but it is to be assumed that most of them had been in use for some time prior to the publication of the encyclopedia and we can be reasonably sure that many of them were developed during the Renaissance period. This encyclopedia is highly recommended to those interested in the historical aspects of production methods. Another source of equal interest is *Diverse et Artificiose Machine* by Ramelli published in 1588.

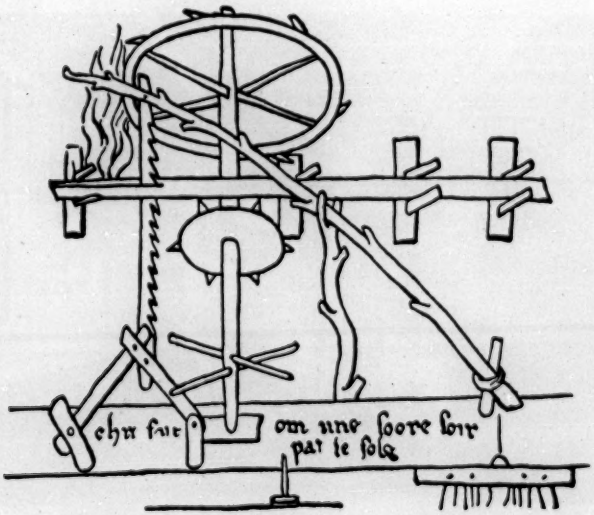

FIG. 4.

Probably the first practical use of the flat belt was on multiple spindle spinning frames, both hand and power operated. On one hand-powered machine illustrated by Diderot ten vertical spindles were arranged in an oval so that one belt could be used without the necessity of idlers to keep the belt in contact with all of the spindles. On a larger machine which was power-driven the spindles were arranged in two straight rows of 24 each, with a single belt driving them all aided by idler pulleys between spindles to increase the arc of contact. All of these spinning machines employed the flyer invented by Leonardo.

That power distribution was a fairly well-known art by the 18th century is clearly indicated by the many illustrations in Diderot's

Encyclopédie which show a wide variety of methods for driving production machinery. Ropes or round belts were used between shafts where the torque was not high, such as in the grinding department of a cutlery, and were usually crossed to increase the arc of contact between belt and pulley. One illustration shows two ropes in parallel, thus anticipating the V-belt drive which is so popular today. Where water power was not available, horses or other animals were hitched in a variety of ways to obtain the necessary power. The most common method is illustrated in Fig. 5, but animals were also hitched to various types of treadmills to rotate mill stones and to provide the necessary

FIG. 5.

power for drilling and boring operations in metal and woodworking shops.

The four-horse capstan shown in Fig. 5 was used to drive two mill stones in a brewery as well as to provide power for lifting grain to the grinding floor. A similar capstan was used in a lead rolling mill to reduce lead billets to sheets. In this machine an ingenious clutch was used to reverse the direction of rotation of the rolls, permitting the horses always to travel in the same direction.

Great ingenuity and inventiveness was demonstrated by the Renaissance engineers in the development of water works for their cities.

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FIG. 6.

Figure 6 shows the details of a rotary pump connected to an undershot water wheel by a chain running on wooden sprockets. This illustration is from *Diverse et Artificiose Machine* by Ramelli, published in 1588, and

is the first practical utilization of a chain drive following its invention by Leonardo da Vinci. The details of the pump are particularly interesting because a well known vacuum pump on the market today utilizes the same construction. Ramelli shows two other rotary pumps, both of which have modern counterparts.

DEVELOPMENT OF STEAM POWER

It did not take long after the introduction of mechanical processes for manufacturers to start looking for ways to take physical labor out of all of their operations. In England, coal was an important commodity, and as the mines began to get deeper the problem of pumping water out of them became serious. Many mines had to be abandoned because of the difficulty of pumping water out of them with the inadequate equipment available. Some mines used mechanical pumps operated through oscillating cables connected to the crank of a water wheel, but obviously a stream had to be readily accessible for this system to be practical. In 1628 the Marquis of Worcester invented a pump which was called the "water commanding engine." This engine lifted and forced water out of the mines by the direct action of steam on the water. Condensation caused water to be drawn into a receiver from the bottom of the mine and direct pressure from the boiler into the receiver forced the water out of it and susbequently out of the mine. The receiver necessarily had to be located near the bottom of the mine and, for convenience, the boilers as well. The relatively high boiler pressures required to lift water out of deep mines caused boiler failures. In the event of a failure of any kind, the whole apparatus was flooded and the mine had to be pumped out by hand before the steam apparatus could be utilized again.

Of greater significance in the development of the steam engine was the Newcomen atmospheric pumping engine. In this engine, steam was admitted to a cylinder at atmospheric pressure and was followed by a spray of water which condensed the steam, thus forming a vacuum. Atmospheric pressure then forced the cylinder downward. The cylinder was connected to a working beam, whose other end was fastened to a pumping rod which could go as deep into a mine as necessary. This engine was strictly a pumping engine and was wholly unsuited to the development of rotary motion. It had a distinct advantage in that the boiler could be outside of the mine and that the boiler did not have to withstand high pressure. By 1772 engines up to 75-in. bore with 96-in. stroke had been built and were rated up to 75 hp. While these engines were somewhat wasteful of fuel they continued to be used as late as 1830, because fuel was so cheap and because the pumps were so reliable.

The development by Watt in 1765 of a condenser separate from the steam cylinder, resulted in higher efficiency for the Newcomen engine.

Later his invention of the double acting cylinder, utilizing steam pressure to produce work in both directions, greatly increased the efficiency of the steam engine and made it possible for the development of rotative engines. In introducing the rotative engine, Watt had to circumvent a previous patent, covering the use of the crank for the development of rotative power, issued to Wasbrough in 1779. Wasbrough failed to make practical use of his development because his work was confined to Newcomen engines. The final development of the rotative engine permitted the use of power in plants away from water and, coming as it did, at the time when mechanization of textile processes was being achieved, it is not surprising that within a year or two after the development of a steam engine prime mover, it was used in a textile mill. During the next 100 years of use, the steam engine was improved only in efficiency and in detail. Engines were speeded up, and improvements in machining methods made possible more accurate cylinders and bearings. It is worthy of note that the methods of boring cylinders were so crude in the early days of steam engine manufacturing that Watt had to tolerate an error of $\frac{3}{8}$-in. in the bore of a cylinder.

Steam engines did not immediately displace water wheels as a source of power. In the United States the division of power was 64 per cent steam and 36 per cent water in 1880; however, in the next 10 years 90 per cent of the added power was by steam.

The perfection of the water turbine by Fourneyron of Paris in 1832 was regarded as equally important as Watt's steam engine. Prior to this development, water power was limited to relatively crude undershot and overshot water wheels and the amount of power that could be developed by any one unit was limited to around 15 to 20 hp. With the successful construction of the turbine it became possible to increase the power to between 75 and 100 hp. with relative ease and, as we know, the modern turbine has practically unlimited capacity.

It was about this same time, namely 1831, that Faraday discovered the laws of electromagnetism and developed the dynamo, which marked the beginning of the use of electric power. As the dynamo and electric motor gradually improved in efficiency, increased in size, and advanced in operating characteristics, they gradually surpassed all other types of prime movers.

INTRA PLANT POWER TRANSMISSION

The best factual data point to the fact that in the 14th, 15th, and 16th centuries, most power transmission inside of plants was accomplished by open wooden gears such as have been previously illustrated or by means of belt drives using round rope made of rawhide or hemp.

In the 18th century, after the steam engine began to find its place in plants and also as the wooden gears began to be replaced by cast

toothed iron gears, main line shafts carrying considerable horsepower were driven almost entirely by gears, and belts were used only to drive individual machines from the main line shaft. This was largely a result of the inability of the existing belt drives to transmit sufficient power at the low speeds in use at that time. As steam engines became capable of operating at somewhat higher speeds and as the horsepower being transmitted became larger, the crude gears became very objectionable and in about 1850 in Belfast, Ireland, the multiple rope transmission was first tried out and in a very short time became very popular in England and in United States.

It is a curious coincidence that rope drives had almost completely displaced open gear drives in many of the mills in England, particularly for transmission of power from steam engines, just about the time when a more complete understanding of the proper tooth form for gears and also when the technique of cutting gears had become known. However, the trend towards belt drives had accelerated to such an extent that even though it was possible to make gears that were reasonably quiet, the general acceptance of ropes, and the satisfaction with their performance, practically eliminated gears from use. However, there are still some mills in England using open gear drives from the main engine and completely throughout the plant from one lineshaft to another. It is generally felt that the gear drives are more efficient than rope or belt drives. Their disadvantages are that they are noisy, somewhat dirtier and require a fair amount of lubrication. Whereas gears were abandoned in 1850 because of their noise, and inability to handle high speeds, today super precise gears are the only possible means of transmitting power from turbines running as high as 30,000 rpm.

The first flat leather belt for use on a group drive or a drive from a single engine to a multiplicity of line shafts, was made in Lowell, Massachusetts, in 1828. This drive was from a large waterwheel to a series of 14 line shafts. An 18-in. leather belt, over 300 ft. long, was used and the belt inter-twined between the various line shafts so that each line shaft had to carry a total belt pull equivalent to the full horsepower of the water wheel. Since that time it has been learned that it is more economical to employ a series of belts and to drive one line shaft from another, each succeeding belt carrying only the power required by the remaining shafts. To have a separate drive from the engine to each shaft is even better. When electric motors were perfected sufficiently to become the principle type of prime movers, rope drives rapidly gave way to flat belt drives which were better suited to the high speed required by electric motors. During the last fifty years flat belts and group drives have been the principle mode of power transmission, until recently when individual motorization and V-belt drives have been the vogue on most new equipment.

INTER PLANT POWER TRANSMISSION

In the 19th century a number of systems for the distribution of power between plants were tried and discarded. Each served its respective function for a time before electrical power distribution finally was adopted universally and displaced the other systems for inter-plant power distribution.

The five major competing systems other than electricity were: high pressure water, air, cable, steam and gas.

High pressure water as a means of power distribution was started in England by Lord Armstrong about 1840. The pressure most commonly used was 750 lb. per sq. in. The pressure was generated by plunger pumps driven either by water wheels or by steam engines. Plunger type accumulators were used to increase the instantaneous horsepower capacity of the system. The water was used to operate cranes, dock gates, and to drive piston motors. The largest installation was in London, where the number of users was approximately 2000, and the capacity was 2600 hp.

The small amount of power per customer gives a clue to the usage for such a system. Water power was found to be effective and reasonably efficient for intermittent usage, but could not compete with steam engines for continuous usage. Numerous practical difficulties developed, such as: dirty water, and the necessity for filters; corrosion and clogging of the pipes; and freezing of the mains in severe weather. However, the fundamental principle is still in use today on large hydraulic press installations, showing that for particular purposes the system is sound.

Air as a means of power distribution was started in 1845, and the first really significant installation was made for operating the boring machinery for the Mont Cenis Tunnel. Shortly thereafter it was adopted quite generally for use in coal mines, where its natural advantages of safety and ventilation made it the most popular system for many years. In 1885 a large vacuum system was installed in Paris. The motors were worked by atmospheric pressure, and exhausted into pipes in which a vacuum was maintained by air pumps at the central station. The amount of air used was measured by meters. In the 1890's air appeared to be the major contender with electricity as a means of distribution of power throughout a city. It was not seriously considered by factories, since they could afford to develop their own power by steam engines, and distribute mechanically as will be explained later. But, for the small user, air power was superior to water power, largely because air was more readily available, cleaner, and its distribution cheaper. Also, water power had the disadvantage that the amount of water used was the same regardless of load, whereas with air, the amount required would vary with respect to load by altering the cutoff.

One of the most interesting and ingenious uses of air was installed in Paris and Vienna in 1870, for operating over 8000 clocks by means of an air impulse of 20 seconds duration once each minute. The air mains were $\frac{5}{8}$ to $\frac{7}{8}$ in. in diameter and the service pipes were $\frac{1}{4}$- to $\frac{3}{8}$-in. diameter.

The vacuum system sufficed in Paris for domestic use, but as demand for use to operate motors increased a high pressure system of 8000 hp. was installed to operate at about 100-lb. pressure. Numerous other European cities employed air for power distribution, until the economy of electrical distribution became so obvious that the use of air could no longer be justified.

Telodynamic Transmission was the name given to the transmission of power by steel cables passing over large grooved sheaves. This system was first tried out in 1850 by a Mr. M. C. F. Hirn in Colmar, Alsace to supply power to some building approximately 86 yards from the single steam engine available. He first tried using a steel band 2 in. wide and 0.04 in. thick, but the wind set the band into vibrations and the pulley guides tore the belt at the joints. It worked for 18 months delivering 12 hp. He then tried $\frac{1}{4}$-in. wire cable instead of the band using the same pulleys with a $\frac{1}{2}$-in. groove turned in the rim. The drive operated for many years. A second drive to a distance of 256 yards with a $\frac{1}{2}$-in. cable over $9\frac{1}{2}$-ft. pulleys running at 92 rpm. transmitting 50 hp. was erected.

Various installations were made all over Europe and in Russia until electric distribution reached a state of perfection in about 1900. On relatively short drives up to approximately 500 yards, the efficiency might be as high as 93 per cent, but falls to 60 per cent for 5000 yards. The cables and pulleys suffered a good deal from the weather, and the cables had to be replaced almost annually. First cost was high due to the necessity of heavy piers at least every 600 ft. Another disadvantage of the system for distribution of power from a central source to a large number of customers was the impossibility of measuring the amount of power used by each customer.

Steam for heat and power purposes was first distributed on a commercial basis in New York City in 1881 following a study of the problem by Dr. C. E. Emery starting in 1869. The steam pressure was 80 lb. and approximately 20,000 hp. was delivered from two stations. The system was tried out for heating purposes only in 1877 by Birdsill Holly in Lockport, where by 1879, 16,000 ft. of pipe line had been laid. The only advantage of steam distribution was the elimination of boiler investment and maintenance by the consumer, and this of course was only economically sound for small users or intermittent users.

Gas for power purposes as well as for heating and lighting was in use from about 1880 in England and United States. The gas was mostly illuminating gas, and was used in Otto cycle engines for various purposes.

In London, the first current for electric lighting was generated by dynamos, belt driven from two-cylinder Otto cycle gas engines of 60-hp. capacity.

It is significant to note that every one of the systems of power distribution developed in the late 19th century has survived in one form or another. High pressure water with an accumulator is still considered the most efficient means for operating large hydraulic presses. Air, while not used for inter-plant power distribution, is one of the most effective and convenient means of driving hand tools. For operating riveters, hammers and rock drills, nothing has been found to equal it. The convenience of air power on spot welders, jigs, die cushions, paint sprayers, and a host of other uses makes it obvious that it is here to stay. The Telodynamic cable transmission system has survived only in the form of the V-belt which today is the most popular method of power take-off from a motor. However, the system has not survived in any form for power distribution from one building to another or from one plant to another. The cable system for outdoor transmission was followed by rope transmission indoors. Rope transmission was replaced by leather or rubber flat belts, and later and much more gradually plants driven by a single source of power broke up their line-shafts into smaller units individually motor driven, and a great many have eliminated group drives altogether in favor of a separate motor at each machine.

In perspective, it becomes clear that changes in methods of power transmission did not occur because of any whimsical popularity of one form of power transmission over another, or because one manufacturer did a better job of advertising than another, but because the particular system in vogue at any one time represented the best compromise for the industry, the materials, the knowledge, and the economics of the era. It is probable that future history will follow the same course as past history and that we can expect that our methods of power transmission will change as the requirements of industry evolve.

There is a considerable tendency for engineers and manufacturers to be very proud of the advancements of our day and to somewhat assume that our forefathers were pretty backward in almost everything they did. This study has indicated to the writer that our forefathers were extremely brillant mechanics and that considering what they had to work with they were equally as intelligent as our best engineers today.

It was Galileo who said that he was able to do the things he did and make the contributions to science he did, because he was standing on the shoulders of giants. Certainly if Galileo could make that statement, we should humble ourselves to the same extent and recognize that we have achieved our mechanical wonders because we are standing on the developments of our forefathers who gave us a sound platform of achievement on which to build further.

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V.24
1949

GRAPHICAL ANALYSIS OF IMPACT OF BARS STRESSED ABOVE THE ELASTIC RANGE*

BY

KALMAN J. DEJUHASZ[1]

ABSTRACT

A number of impact problems of engineering interest are analyzed by means of a graphical method previously developed by the author. Problems considered comprise: impact at constant velocity of finite duration applied to one end of a bar, the length of the bar being infinite; bars of finite length, the other end being free, and the other end being fixed or restrained; impact stresses below yield stress (elastic range), and impact stresses above yield stress (plastic range). The history and gradient of stress and of velocity are represented in three-dimensional diagrams. The energy expended in impact, and its distribution into energy of plastic deformation, and into residual kinetic and elastic stress energy are determined. The total residual permanent strain is determined. The general treatment is supplemented with numerical examples.

INTRODUCTION

Impact is a special case of the broad group of dynamic phenomena in which a force P having a defined history function $P = f(t)$ is exerted on a body of m mass. The present inquiry will be restricted to direct and central impact, that is, the motion is assumed to be perpendicular to the striking surfaces, and the force is assumed to be directed along the line joining the mass centers; furthermore, the impacted body is assumed to be initially at rest. As for any dynamic phenomenon, also for impact, the equality of impulse and momentum holds good and it can be written:

$$P\,dt = d(mv).$$

The distinguishing features of impact, as compared with other dynamic phenomena, are that the force is large, its duration is very short, and it is applied to a point or to an area on the surface of the body.

Impact phenomena formed the subject of theoretical and experimental studies by a long line of investigators, beginning with Galileo and possibly even earlier. The theories have, of necessity, used various degrees of approximation, falling into two groups: considering the bodies (*a*) rigid, and (*b*) yielding.

Impact of Rigid Bodies

In rigid bodies the particles are located at constant and unalterable distances from one another, and under direct and central impact, at

* Presented before the Seventh International Congress of Applied Mechanics, September, 1948, at the Imperial College of Science and Technology, London, England. It is based on work performed for the Department of the Army, Office of the Chief of Ordnance.

[1] Professor of Engineering Research, Engineering Experiment Station, The Pennsylvania State College, State College, Pa.

any given instant of time, all particles will possess the same velocity, that is, any change of velocity applies to the entire body. Therefore the principle of momentum can be written:

$$\int_0^t P\,dt = \int_0^v mdv = m\int_0^v dv.$$

It has been early recognized, however, that the assumption of an ideally "rigid" body introduces conceptual contradictions and inconsistencies. The dimensions of the body are finite (that is, not infinitesimally small) and its particles are located at various distances from the point of application of the force (on the outside surface of the body); therefore an infinite velocity of propagation of the disturbance from particle to particle within the body has to be assumed, and consequently also infinitely large stresses between the particles.

Impact of Yielding Bodies

These contradictions are eliminated by the realistic assumption that the particles of the body are capable of displacement relatively to one

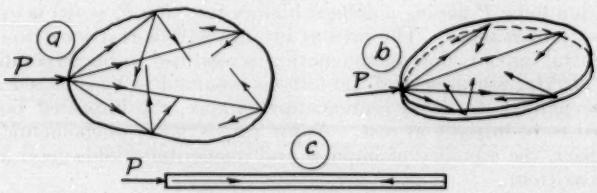

FIG. 1. Reverberations of a disturbance in (a) a three-dimensional body, (b) a two-dimensional disk, and (c) a one-dimensional bar.

another whereby a finite stress is introduced between them. A consequence of these properties is that the velocity of propagation of a disturbance from particle to particle has a finite value. In the case of a yielding body, therefore, the impact can be visualized in a manner that to the particle at the point of application of the force P a finite stress and velocity is imparted, which are transmitted to other adjacent particles with the velocity of propagation, the waves of disturbance radiating in all directions from the point of application of the force as illustrated in Fig. 1(*a*). As these disturbances arrive at the boundaries of the body the stresses are relieved and the velocities changed in accordance with the boundary conditions of the body, and these new disturbances radiate again in all directions from the points of arrival of the first waves. Thus the waves of disturbance bounce back and forth within the confines of the body. After several reverberations of these waves of stress and velocity, every particle will possess a stress and

velocity which are resultants of the several stress and velocity waves to which the particle has been exposed. Figure 1(*b*) illustrates this phenomenon in a flat, disk-shaped body in which the waves are propagated in two dimensions only, and Fig. 1(*c*) is a bar in which the waves are propagated in one dimension only. Thus, in the case of a yielding body a finite change of velocity is imparted, not to the entire mass, but only to an infinitesimal part of it, and the principle of momentum can be written:

$$\int_0^t P\,dt = v\int_0^m dm.$$

After the cessation of force the body will possess a mean state of stress and velocity, upon which, in general, is superimposed a state of fluctuating stress and velocity between the particles themselves. The energy represented by this superimposed vibration and that due to permanent deformation, is debited against the total energies of the bodies before the impact. For this reason the kinetic energy after the impact will be, in general, less than the energy content of the bodies before impact, even in the absence of damping.

In the dynamics of most bodies of engineering importance (for example, crank and connecting rod mechanisms, and other elements of machinery) the dimensions are small and the duration of the application of force is long relative to the duration of the reverberation of the disturbance within the body. Therefore the stress and velocity condition is rapidly equalized within the body, the phenomena occurring during this equalization are of no interest, the permanent deformation is nil, the superimposed vibrations represent a negligible amount of energy, and no serious error is incurred by assuming the body as rigid.

There are, however, cases in which this so to speak "macroscopic" view of the dynamic phenomenon is inadequate, and it is necessary to study the progress of the phenomena in "microscopic" detail. This is desirable, in particular, whenever the period of reverberations is not negligible in comparison with the duration of force application. This condition prevails in the case of large bodies as the Earth (earthquakes, natural and artificial), and also in engineering devices, such as long trains (starting and stopping), pump rods in oil well machinery (periodic forces and motions), helical springs in valve gears and in guns (surges), and in impact (hammers, projectiles), to mention some specific examples.

For the rational design of such engineering devices the clear understanding of these phenomena is highly desirable. However, experimental investigation is extremely difficult owing to the smallness of motions, and the shortness of time in which they occur. Recourse has to be taken, therefore, mainly to theoretical methods of attack.

In recent years growing recognition has been given to the theory of this group of problems, as evidenced by the literature on impact of

bars, which is probably the simplest species of this group, the conditions of which can be definitely stated, the disturbances in which are essentially one-dimensional and which is also open, to a fair extent, to experimental investigation as well.

Yielding materials are characterized by their stress-strain relationship, part of which, within the elastic range, is linear, beyond which in the plastic range the relationship is curvilinear.

Previous engineering literature on impact problems has treated mainly phenomena below the elastic limit of materials; that is, in the stress range for which the law of proportionality of stress and strain is valid, there is no permanent deformation and the velocity of propagation of a disturbance is constant. In an earlier paper (1942) DeJuhasz[2] has summarized the history of engineering treatments of elastic impact and extended the work of earlier investigators to some novel problems by means of a graphical method of analysis.

Until recently, little attention has been paid to impact phenomena occurring above the elastic limit, that is, in the plastic range, for while the proportionality of stress and strain is no longer valid, permanent deformation occurs, and the velocity of propagation of a disturbance is no longer constant but depends on the value of stress and strain. Probably the earliest work dealing with this field is Donnell's treatise (1930) in which a paragraph is devoted to a brief but basic and lucid exposition of plastic impact phenomena. A later discussion by Angus (1942) points out the need for a treatment of impact in the plastic range and refers to the analogy between this phenomenon and water hammer. Recently, however, an increasing need has been felt for a theory of plastic impact in order to provide a systematic basis for the understanding and interpretation of notched bar impact tests, performance of elements of machinery under dynamic loading, interaction between projectile and armor plate, and phenomena produced by other ordnance devices. Wartime stimulus resulted in a series of papers and official reports on this subject by von Kármán, White, Griffis, Duwez, Clark, Bohnenblust and associates, which contributed to the clearing up of these phenomena by experimental, mathematical, and to some extent by graphical methods. It is felt, however, that these theories and methods need further elucidation, extension and application to complex yet technically important phenomena.

The present paper is an attempt to clarify the theory of plastic impact and to extend its applicability by means of a graphical method of analysis which has been previously developed by the author and used for elastic impact, and which is herewith adapted also for plastic impact.

For the sake of completeness the essential ideas, concepts and procedures of the graphical analysis will be given here.

[2] References are included in the bibliography appended to Part II of this paper.

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GRAPHICAL ANALYSIS

Essential Concepts

It is proposed to investigate the problem of a long bar, having given material properties, to one end of which a velocity in the axial direction according to a given history law $v = f(t)$ is imparted; the mechanical state of the bar is to be determined for every cross section and for every instant of time.

The material properties are defined by the density, ρ, and the stress-strain characteristics, $p = f(\epsilon)$. A cross section is identified by its distance x from one reference cross section, say one end, of the bar. An instant of time is defined by the number of seconds t elapsed after

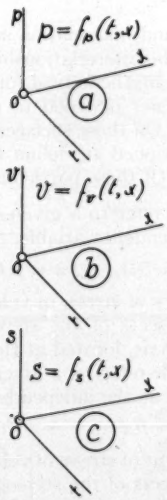

FIG. 2. Coordinate systems for stereograms of (a) stress, (b) velocity, and (c) displacement.

the beginning of time reckoning for which $t = 0$. The "mechanical state" is defined by the stress p, velocity v, strain ϵ, force P, displacement s existing in a cross section. Of these "coordinates of state" main attention will be given to the stress p and to the velocity v, because the other coordinates can be derived from these two as will be shown later. It will be assumed that the mechanical state of all particles in one cross section is the same at one given instant. The change of state of a cross section from an initial state p_1, v_1, to a new p_2, v_2 state will be called a "disturbance".

A dynamic phenomenon in a bar can be completely described by

giving the coordinates of state for every cross section, and for every instant of time. This can be accomplished mathematically by functions of the type:

$$p = f(t, x), \qquad v = f(t, x),$$
$$s = f(t, x), \qquad \epsilon = f(t, x), \qquad P = f(t, x),$$

expressing the coordinates of state as functions of two variables, t and x.

In geometrical terms such functions represent surfaces established within the framework of coordinate systems as shown in Fig. 2 in which the coordinates of state p, v and s are erected, as vertical ordinates, over the t–x plane as base. Such three-dimensional diagrams will be termed "stereograms", and in particular, stereogram of stress, of velocity, of strain, etc.

For technical thinking and imagination such stereograms provide a far clearer visualization of the interrelationships of three variables, than is possible to obtain from a mathematical formula. They even can be actually constructed of plaster or wood to represent a dynamic phenomenon with given data. On these surfaces then lines may be drawn, or the surfaces can be sectioned to define functions of *two* variables which may be of interest. Of these particular interest attaches to the:

(*a*) *history curves* which refer to a given cross section, having only the time, t, as independent variable, e.g.,

$$p = f(t)_x, \qquad v = f(t)_x, \qquad s = f(t)_x,$$

expressing the history of stress, of velocity and of displacement. These are the intersects of the stereograms with planes perpendicular to the x-axis, located at the given x-coordinate.

(*b*) *gradient curves* which refer to a given instant of time, having only the distance, x, as the independent variable, e.g.,

$$p = f(x)_t, \qquad v = f(x)_t, \qquad s = f(x)_t,$$

expressing the gradient of stress, of velocity, and of displacement. These are the intersects of the stereograms with planes perpendicular to the t-axis located at the given t-coordinate.

Construction of Stereograms

The stereograms can be constructed with the aid of two two-dimensional diagrams, namely:

(*A*) The t–x diagram which is termed the "location diagram", in which a point identifies an instant of time t, as reckoned from a reference instant (for example, from the beginning of impact), and a cross section of the bar, located at the distance x, as measured from a reference cross section (for example, from the impact end of the bar).

(*B*) The v–p diagram, termed the "diagram of state" in which a point identifies a "mechanical state", that is, co-existing values of

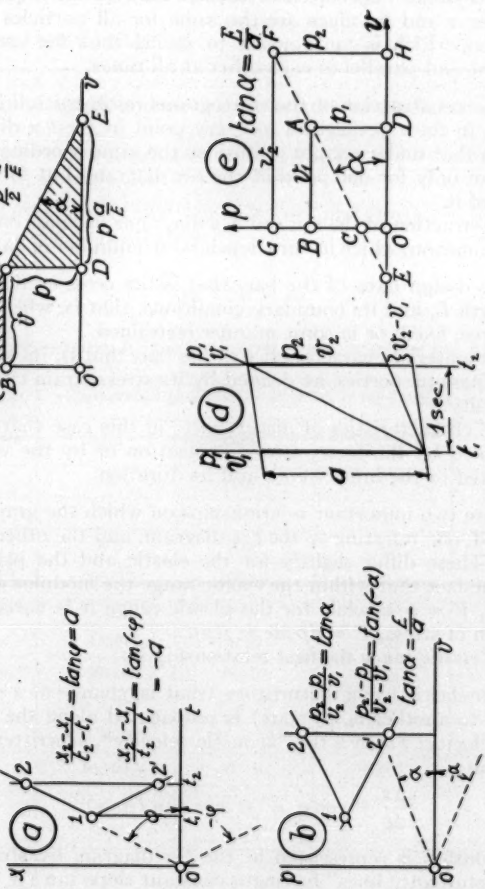

FIG. 3. Representation of an elastic disturbance.

(a) Disturbance lines 1–2 and 1–2'.
(b) Directrices 1–2 and 1–2'.
(c) Energy relations.
(d) Displacement of cross section during change of velocity.
(e) Energy change through change of state.

velocity and stress. As stated before, we restrict our inquiry to cases in which the v and p values are the same for all particles in a given cross section, which is tantamount to saying that the cross sections remain plane and parallel to each other at all times.

Thus the construction of the stereograms resolves itself into assigning a point in the v–p diagram to every point in the t–x diagram. It will be seen that under certain conditions the same coordinates of state are valid not only for one *point* in the t–x diagram, but for an area or "domain" of it.

The construction of the t–x and v–p diagrams depends on the course of the phenomenon, which in turn depends on a number of data, namely:

(*a*) The design data of the bar, that is, its cross sectional area F, length L, and its boundary conditions, that is, whether the end is free, fixed, or in some manner restrained.
(*b*) The material characteristics of the bar, that is, its strength and stiffness properties, as defined by its stress-strain curve, and its density.
(*c*) The characteristics of disturbance, in this case that of impact, defined by the force, stress, applied on or by the velocity imparted to the impact end, and its duration.

There are two important relationships on which the graphical analysis is based, one referring to the t–x diagram, and the other to the v–p diagram. These differ slightly for the elastic and the plastic range, owing to the fact that within the elastic range the modulus of elasticity is constant, $E = p/\epsilon$, while for the plastic range it is variable, and is the function of stress, $E = dp/d\epsilon = f(p)$.

For the *elastic range* the first relationship is:

1. In an elastic bar a disturbance (that is, change of a pre-existing v_1, p_1 state to another v_2, p_2 state) is propagated along the bar with a constant velocity, which is the "acoustic velocity", a; written in mathematical form:

$$\frac{\Delta x}{\Delta t} = \text{const} = \pm a = \tan(\pm \varphi). \tag{1}$$

This relationship is represented in the t–x diagram by straight lines, termed "disturbance lines" having a constant slope $\tan(\pm \varphi)$ towards the t-axis, as shown in Fig. 3(*a*). The positive sign is valid for disturbances the location x of which increases with increasing time.

The acoustic velocity is interrelated with the modulus of elasticity E and the density of material ρ by the following equation:

$$a^2 = \frac{E}{\rho}. \tag{2}$$

(For example, for steel the acoustic velocity is about: $a = 203{,}000$ in sec.$^{-1}$).

The second relationship is:

2. In an elastic bar a change of velocity is accompanied by a proportional change of stress, and *vice versa;* written in mathematical form:

$$\frac{\Delta p}{\Delta v} = \text{const} = \pm \frac{E}{a} = \tan (\pm \alpha). \tag{3}$$

The value E/a is termed the "surge factor" and it can be expressed by the characteristics of the material:

$$\frac{E}{a} = \sqrt{E\rho} = \rho a. \tag{4}$$

(NOTE: The expression E/a is preferred, because then the numerators,

TABLE I.—*Characteristic Quantities of Materials in the Elastic Range.*

Characteristic \ Material		Steel	Copper Annealed	Aluminum 24 ST	Oak (Red) 80% Moist.
γ		7.8	9.0	2.72	0.57
w	lb. in.$^{-3}$	.282	.325	.098	.0206
	kg. m.$^{-3}$	7800	9000	2720	570
ρ	lb. in.$^{-4}$ sec.^{2}	.000729	.000841	.000254	.0000533
	kg. m.$^{-4}$ sec.^{2}	795	917	278	58.1
V	in.^{4} lb.$^{-1}$ sec.$^{-2}$	1370	1190	3940	18,750
	m.^{4} kg.$^{-1}$ sec.$^{-2}$	.00126	.00109	.00360	.001725
E	lb. in.$^{-2}$	30×10^6	14×10^6	10×10^6	1.3×10^6
	kg. m.$^{-2}$	2.11×10^{10}	$.985 \times 10^{10}$	$.704 \times 10^{10}$	$.0915 \times 10^{10}$
a	ft. sec.$^{-1}$	16,900	10,750	16,600	13,000
	in. sec.$^{-1}$	203×10^3	129×10^3	199×10^3	156×10^3
	m. sec.$^{-1}$	5150	3270	5050	3960
$\frac{E}{a}$	$\frac{\text{lb. in.}^{-2}}{\text{in. sec.}^{-1}}$	148	109	50.3	83.5
	$\frac{\text{kg. m.}^{-2}}{\text{m. sec.}^{-1}}$	4.10×10^6	3.01×10^6	1.40×10^6	2.31×10^6
El. Limit	lb. in.$^{-2}$	30–260,000	~ 3500	$\sim 40{,}000$	$\geqq 800$
	kg. m.$^{-2}$	$2\text{–}180 \times 10^6$	$\sim 2.5 \times 10^6$	$\sim 28 \times 10^6$	$\geqq .56 \times 10^6$

and the denominators, respectively, of both sides of Eq. 3 will have the same dimension.)

This relationship is represented in the v–p diagram by straight lines, termed "directrices" having a constant slope tan ($\pm \alpha$) toward the v-axis, Fig. 3(b). The positive sign is valid for disturbances in which the velocity and the stress both increase or both decrease.

(For example, for steel the surge constant is 148 lb. in.$^{-3}$ sec., which means that a velocity change by 1 in. sec.$^{-1}$ imposed on a steel bar is accompanied by 148 lb. in.$^{-2}$ change of the stress.)

The significant strength properties of several materials are given in Table I.

The validity of these relationships (1) and (3) is restricted to such stress values as lie below the elastic limit of the material (for steel about 30,000 lb. in.$^{-2}$, for annealed copper about 3500 lb. in.$^{-2}$) and to such values of velocity which are far below the acoustic velocity, as it will be explained and derived later.

Energy in the Elastic Bar

Areas $v \cdot p$ in the v–p diagram have the dimension of lb. in.$^{-1}$ sec.$^{-1}$, that is, that of work absorbed by or liberated by a bar of unit cross-sectional area during 1 sec. Because during 1 sec. a length a is affected by a disturbance, therefore it is also correct to say that an area represents the work absorbed by or liberated by a bar of unit cross-sectional area having a length a. Triangular areas, defined by a directrix drawn from a v_1, p_1 state (point A, Fig. 3(c)) to its intersection with the v and p-axes represent the potential, and kinetic energy, respectively, contained in a bar of unit cross-sectional area and a length a, in virtue of its stress p and velocity v. Thus, in Fig. 3(c), the potential energy of the bar of unit cross-sectional area and of length a having a stress p (point A) is represented by the hatched triangle $\triangle ADE$:

$$H_p = \frac{p^2}{2}\frac{a}{E} = \triangle ADE$$

because: $p/E = \epsilon$ = strain = change of unit length; $a\,\epsilon$ = change (displacement) of length a; therefore $H_p = (p/2)\,a\,\epsilon$ = potential energy. Likewise, the kinetic energy is represented by the hatched triangle $\triangle ABC$:

$$H_v = \frac{v^2}{2}\frac{E}{a} = \triangle ABC,$$

because $E/a = a\rho$ = the mass of a bar of length a of unit cross-section. For a bar of length L, of unit cross section, the corresponding energy values will be L/a-times the hatched areas:

$$U_p = \frac{L}{a} \triangle ADE, \qquad U_v = \frac{L}{a} \triangle ABC,$$

L/a being the interval of time necessary for a disturbance to traverse a bar length L, from one end to the other.

These properties of the v–p diagram are useful for determining the energy content of a bar, by multiplying the areas of the respective

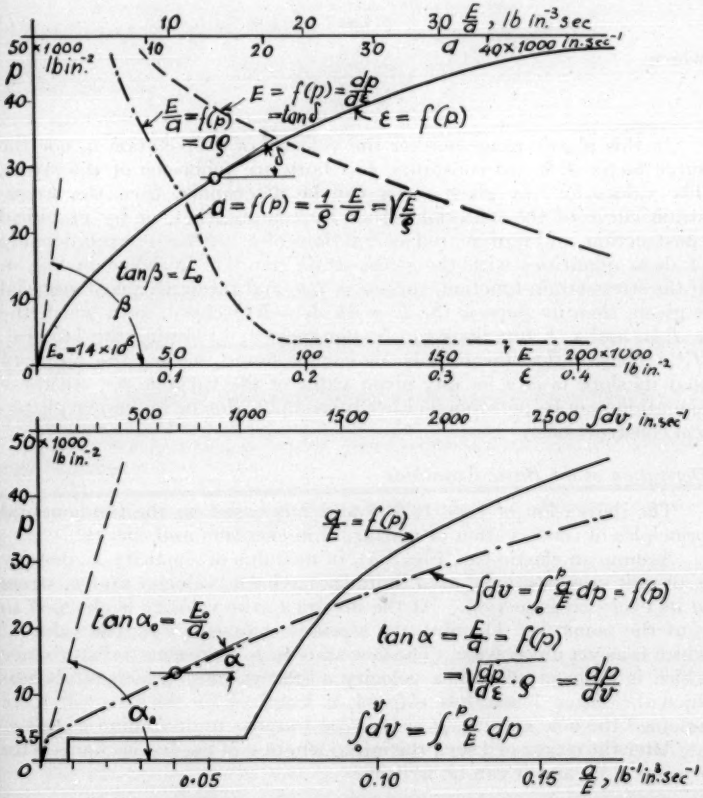

FIG. 4. Derivation of significant elastic and plastic relationships from the stress-strain curve (for annealed copper, according to White and Griffis, ref. 34).

triangles with the cross-sectional areas of the bar, and the length portions characterized by the given v, p coordinates.

For the *plastic range* the Eqs. 1 and 2 have to be written in differential form:

$$\frac{dx}{dt} = \pm a = \tan(\pm \varphi) = f(p); \qquad (5)$$

where

$$a^2 = \frac{1}{\rho}\frac{dp}{d\epsilon}, \tag{6}$$

and

$$\frac{dp}{dv} = \pm\frac{E}{a} = \tan(\pm\alpha) = f(p), \tag{7}$$

where

$$\frac{E}{a} = \sqrt{\rho\frac{dp}{d\epsilon}}. \tag{8}$$

In this plastic range neither the velocity of propagation a, nor the surge factor E/a are constants, but both are functions of the stress. The values for any given stress can be determined from the stress-strain curve of the material, either by computation, or by graphical construction, and represented as functions of p. (The interrelationship of these quantities with the stress-strain function is shown in Fig. 4. If the stress-strain function, curve $\epsilon = f(p)$ and the density ρ of material is given, then its slope is the $E = dp/d\epsilon = f(p)$ curve, from which the a, E/a, and a/E functions can be determined. Forming the integral: $\int_a^p (a/E)dp = f(p)$ the $\int dv$ curve can be found, having the property that its slope is E/a for any given value of the variable p. All these operations can be performed either by computation or by known graphical constructions.)

Derivation of the Basic Equations

The derivation of Eqs. 1, 3, 5 and 7 is based on the fundamental principles of conservation of matter, of momentum and energy.

Assume an elastic bar, Fig. 3(*d*), of modulus of elasticity E, density ρ, of unit cross-sectional area, initially having v_1 velocity and p_1 stress in its every cross section. At the instant t_1, the velocity is changed to v_2 at the point A. Thereby, the stress is changed to p_2 (the value of which is as yet unknown). The new state v_2, p_2 represents a disturbance which is propagated with a velocity a (the value of which is yet unknown). After 1 sec. has elapsed, a length a of the bar will have assumed the new state v_2, p_2. It is our purpose to determine p_2 and a.

After the elapse of 1 sec., the initial length a of the bar is changed to: $a - (v_2 - v_1)$ and it can be written:

$$\frac{a - (v_2 - v_1)}{a} = \frac{E - p_2}{E - p_1}.$$

Assuming an elastic change, in which the values of p_2 and p_1 are very small in comparison with E, it can be written:

$$1 - \frac{v_2 - v_1}{a} = 1 - \frac{p_2 - p_1}{E};$$

denoting $p_2 - p_1 = \Delta p$ and $v_2 - v_1 = \Delta v$ it can be written:

$$\frac{\Delta p}{\Delta v} = \frac{E}{a},$$

which is identical with Eq. 3. From the postulatum of conservation of momentum, it can be written:

$$(p_2 - p_1)\Delta t = m(v_2 - v_1).$$

Substituting:

$$\Delta t = 1 \text{ sec.}; \qquad m = a\rho; \qquad p_2 - p_1 = \Delta p; \qquad v_2 - v_1 = \Delta v,$$

we obtain:

$$\frac{\Delta p}{\Delta v} = a\rho,$$

which combined with Eq. 3 yields:

$$a^2 = \frac{E}{\rho},$$

giving the velocity of propagation in terms of the properties of the material.

It is to be shown that these relationships satisfy the postulatum of conservation of energy.

For a length of bar a having coordinates of state v, p the energies can be expressed:

$$\text{Kinetic energy} \qquad H_v = \frac{mv^2}{2} = a\rho\frac{v^2}{2} = \frac{E}{a}\frac{v^2}{2},$$

$$\text{Potential energy} \qquad H_p = \frac{ap}{E}\frac{p}{2} = \frac{a}{E}\frac{p^2}{2},$$

that is, expansion of bar from p stress to zero stress, by a travel: $a(p/E)$. If the initial state is $p = 0$, $v = 0$, then: $p = (E/a)v$ and the kinetic energy is equal to the potential energy.

When the state of the bar is changed from state v_1, p_1, to state v_2, p_2 the work done per second (on length a because during 1 sec. a length a of the bar is affected) is p_2v_2. Part of this work is expended in moving the bar against p_1 stress with v_1 velocity, that is, p_1v_1. The balance appears as the change of Kinetic plus potential energies in the bar. It can be written:

$$p_2v_2 - p_1v_1 = \frac{1}{2}\frac{E}{a}(v_2^2 - v_1^2) + \frac{1}{2}\frac{a}{E}(p_2^2 - p_1^2)$$

$$= \frac{1}{2}\frac{E}{a}(v_2 - v_1)(v_2 + v_1) + \frac{1}{2}\frac{a}{E}(p_2 - p_1)(p_2 + p_1).$$

Substituting:

$$p_2 - p_1 = \frac{E}{a}(v_2 - v_1),$$

we obtain:

$$p_2v_2 - p_1v_1 = \tfrac{1}{2}(p_2 - p_1)(v_2 + v_1) + \tfrac{1}{2}(v_2 - v_1)(p_2 + p_1),$$

which, expanded, yields to an identity, q.e.d.

In the v–p diagram for a length of bar a, the kinetic energy is represented, for v_1p_1 state (point A, Fig. 3(e)) by the triangle $\triangle ABC$; and the potential energy by the triangle $\triangle ADE$. Similarly, for the state, point F, the respective triangles are $\triangle FGC$ and $\triangle FHE$. It is readily seen that the difference $p_2v_2 - p_1v_1$ is $FGOH - ABOD = ABGFHD$.

The above derived basic relationships and formulas have been developed by several authors by means of calculus. But the elementary derivation used here is just as rigorous, and it is believed to be easier to follow and visualize.

The previously used mathematical methods are based on the same principles and formulas and therefore the results of mathematical analysis are bound to be the same as those of the graphical analysis, within the limits of computational and constructional errors. In contrast with mathematical procedures the utilization of these formulas for graphical construction of the t–x and v–p diagrams endows the graphical method with a greater clarity of visualization and with wider applicability to complicated cases, as will be illustrated by the examples to follow.

EXAMPLES

General Remarks

Based on the previously given derivations the graphical method will be applied to numerous impact problems: first, involving stresses in the elastic range; second, involving stresses in the elastic and plastic range. Summarizing the previously obtained results the procedure will be:

1. To set up two coordinate systems, the t–x diagram and the v–p diagram.

2. To determine, from the given data of the material, the velocity of propagation $a = \tan \varphi$ and the wave factor $E/a = \tan \alpha$, and to establish in the t–x diagram the direction of disturbance lines, tan $(\pm \varphi)$, and in the v–p diagram the directrices tan $(\pm \alpha)$.

3. From the design data of the problem, that is, the dimensions of the bar, the applied impact stress or velocity, to follow through the phenomena from instant to instant and from point to point in the bar, with the aid of the disturbance lines and directrices, and to determine thereby the points or domains in the t–x diagram, for which a given state in the v–p diagram holds good.

4. To erect the v and p coordinates, as ordinates, over the plane as base, and thereby to obtain the stereograms of velocity and stress; to obtain from the stereogram of velocity, by integrating according to time, the stereogram of displacement.

5. To determine the impact energy, and the energy content of the bar for various portions of the bar and from instant to instant of time.

The examples will be divided into two groups, those below and those above the elastic limit.

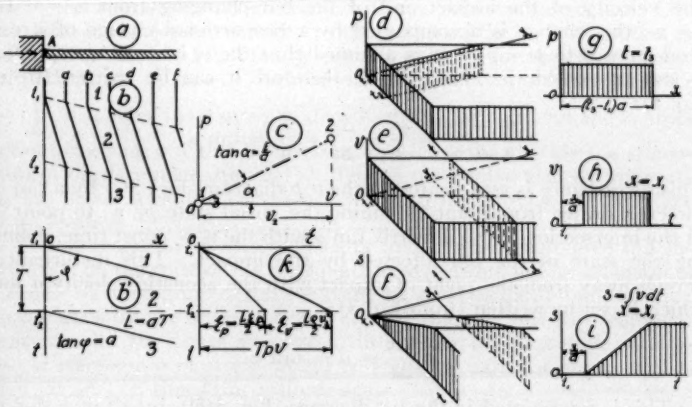

FIG. 5. Elastic impact in compression, bar of infinite length.

(*a*) Schematic arrangement.
(*b*) Displacement of cross sections.
(*b'*) Location diagram (l–x diagram).
(*c*) Diagram of state (v–p diagram).
(*d*) Stereogram of stress.
(*e*) Stereogram of velocity.
(*f*) Stereogram of displacement.
(*g*) Gradient diagram of stress, taken at instant t_3.
(*h*) History diagram of velocity, taken at cross section x_1.
(*i*) History diagram of displacement of cross section x_1.
(*k*) History diagram of energy relations.

I. IMPACT IN THE STRESS RANGE BELOW THE ELASTIC LIMIT

In this range the E, a, and E/a quantities are constant, and therefore the tan φ disturbance lines and the tan α directrices are represented by straight lines of constant slope. The procedures of graphical analysis are, therefore, simple as will be shown in the examples that follow.

Problem 1. Elastic Impact in Compression, Bar of Infinite Length (Fig. 5)

Referring to Fig. 5(*a*) we shall consider a bar of unit cross-sectional area one end of which is subject to impact, and which extends in the

other direction to infinite length, of a material of elastic modulus E, acoustic velocity a, and surge factor E/a. The bar is supported without friction in such a manner that it can move only longitudinally in the direction of its axis. Initially it has zero velocity and zero stress, that is, its coordinates of state are: $p_1 = 0$; $v_1 = 0$. (Positive sign is assigned to velocity towards the right, and to compressional stress.) At $t = 0$ instant a comparatively large mass, having v_2 velocity, comes into contact with the end of the bar to which it imparts the same v_2 velocity, for a time duration T. This disturbance is characterized by the velocity of the impact end of the bar changing from $v_1 = 0$ to $v = v_2$; this change is accompanied by a proportional change of stress from $p_1 = 0$ to $p = p_2$. It is assumed that the v_2 is small enough for p_2 not to exceed the elastic limit; therefore it can be written (from Eq. 1):

$$\frac{p_2 - p_1}{v_2 - v_1} = \frac{p_2}{v_2} = \frac{\Delta p}{\Delta v} = \frac{E}{a} = \tan \alpha.$$

This disturbance is represented in the v–p diagram, Fig. 5(c) by a tan α directrix drawn from point 1 defining the initial state p_1, v_1, to point 2 at the intersection of the directrix tan α with the v_2 = const time, defining the state of the bar affected by the impact. This disturbance travels away from the point of impact with the acoustic velocity a for which it can be written (from Eq. 3):

$$\frac{x}{t} = \frac{\Delta x}{\Delta t} = a = \tan \varphi.$$

This is represented in the t–x diagram, Fig. 5(b'), by a tan φ slope. At the cessation of the impact at $t = T$ instant (according to our initial assumptions), the velocity of the impact end of the bar is reduced to zero, $v_3 = 0$, whereby also the stress is reduced to zero:

$$v_3 = v_1 = 0, \qquad p_3 = p_1 = 0.$$

Figure 5(b) shows the initial cross sections a, b, c, d $\cdots$ as displaced by the impact, the particle velocity of the cross section (v_2 = slope of the heavily drawn lines) and the velocity of propagation (dash-lines). The heavily drawn lines are closer together (measured in the x-direction) in the portion of the bar affected by the impact, indicating the presence of compressive strain, hence compressive stress. Figure 5(b) shows impressively the nature and progress of the impact phenomenon, but it is exaggerated and is not in true scale inasmuch as actually the particle velocity is far smaller than the acoustic velocity. (In the case of steel the acoustic velocity is $a = 203{,}000$ in. sec.$^{-1}$, while the particle velocity corresponding to the elastic limit of 30,000 lb. in.$^{-2}$ is only about 200 in. sec.$^{-1}$, that is, 1/1000th part of the acoustic velocity.) Therefore the location diagram Fig. 5(b') is closer to the truth, giving

the boundaries of the domains in which state 1, state 2, and state 3 (as defined by the v- and p-coordinates of points 1, 2, and 3 of the diagram of state, Fig. 5(c)) exist.

The stereogram of stress, Fig. 5(d), and of velocity, Fig. 5(e), are constructed by erecting the v- and p-ordinates of points 1, 2, and 3 taken from the v–p diagram, Fig. 5(c), over the respective domains 1, 2, and 3 of the location diagram, Fig. 5(b'). The intersect of the stress stereogram, Fig. 5(d), with a plane perpendicular to the t-axis at t_3 instant is the gradient of stress, Fig. 5(g), giving the stress of the entire bar at the t_3 instant. The intersect of the velocity stereogram, Fig. 5(e), with a plane perpendicular to the x-axis at the x_1 cross section is the velocity history, Fig. 5(h), giving the velocity for the cross section for all instants of time. Forming the integral of the history curve: $s = \int_{x_1/a}^{t} v\,dt$ gives the history of displacement, Fig. 5(i), for the x_1 cross section; carrying out this integration for all x-values yields the stereogram of displacement, Fig. 5(f). This is obtainable also by integrating the strain gradient curves according to distance: $s = \int (P/E)dx$ for all t-values.

The stereograms of stress, velocity and displacement give full information on the state of the bar for all cross sections and for all instants of time. A stereogram of force F could be constructed, by multiplying the p-values by the cross-sectional area of the bar; but this would be identical with the stress stereogram in another ordinate scale. Likewise, a stereogram of strain would be identical with the stress stereogram, at an $1/E$-times the ordinate scale.

It can be visualized from these stereograms, that to length $L = Ta$ of the bar velocity v_2 and stress p_2 is imparted by the impact; this wave of length L is propagated along the bar with the acoustic velocity a; when the front of the wave passes over a cross section it changes the state of the cross section from v_1, p_1 to v_2, p_2; after the rear of the wave passes over a cross section, it changes the state of the cross section from v_2, p_2 to v_3, p_3 leaving it again at rest, and free of stress. In the process the cross section had advanced by the displacement $s_2 = Tv_2$.

The history of energy relations is represented in Fig. 5(k); energy is being fed into the bar at a rate of p_2v_2, until the termination of the impact period T; thus the total energy input is: $\mathcal{E}_T = Tp_2v_2$. One half of the energy appears as compression energy: $\mathcal{E}_p = (L\epsilon_2p_2/2)$, where $\epsilon_2 = p_2/E$; therefore:

$$\mathcal{E}_p = L\frac{p_2}{2E} = \frac{Tap_2^2}{2E} = \frac{1}{2}Tp_2v_2.$$

The other half appears as kinetic energy:

$$\mathcal{E}_v = \frac{L\rho v_2^2}{2}, \qquad \text{where} \qquad \rho = \frac{E}{a^2}; \qquad \frac{L}{a} = T; \qquad \text{and} \qquad \frac{E}{a}v_2 = p_2;$$

hence

$$\mathcal{E}_v = \tfrac{1}{2} T p_2 v_2.$$

Problem 2. Elastic Impact in Tension, Bar of Infinite Length (Fig. 6)

The assumptions are similar to those in the previous example, Fig. 5, with the exception that the stress is tensional, that is, negative, and the impact velocity is to the left, that is, also negative. Therefore the

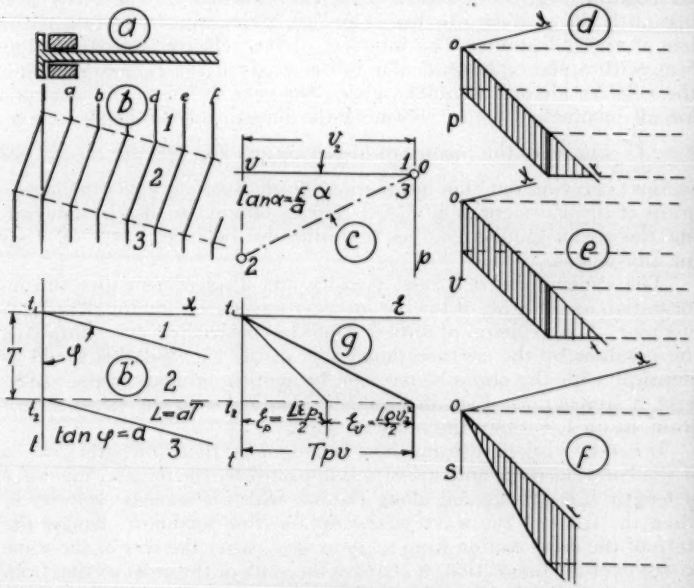

FIG. 6. Elastic impact in tension, bar of infinite length.

(*a*) Schematic arrangement.
(*b*) Displacement of cross sections.
(*b'*) Location diagram.
(*c*) Diagram of state.
(*d*) Stereogram of stress.
(*e*) Stereogram of velocity.
(*f*) Stereogram of displacement.
(*g*) History diagram of energy relations.

point 2 in the diagram of state, Fig. 6(*c*) will be situated in the lower left quadrant, instead of the upper right quadrant of the diagram. In the exaggerated displacement diagram, Fig. 6(*b*), it is visible that the distance between the neighboring cross sections *a*, *b*, *c*, *d* ⋯ is increased (measured in the *x* direction) in the domain 2 affected by the impact, indicating the presence of tensional strain, hence tensional stress. The stereograms of stress, velocity and displacement, Fig. 6(*d*), (*e*) and (*f*)

are also similar to the corresponding ones in the previous example, with the difference that the ordinates are directed downwards, in accordance with the negative sign of the stress, velocity and displacement. The energy diagram, Fig. 6(g), is of identical form as for compressive impact, because both p and v being negative their product is positive.

Problem 3. Elastic Impact in Compression at Variable Velocity, Bar of Infinite Length (Fig. 7)

A compressive impact is assumed, at variable velocity, the history of impact velocity being of triangular shape as shown in Fig. 7(b'); according to the v–p diagram Fig. 7(c), also the impact stress has a triangular history diagram; mathematically stated:

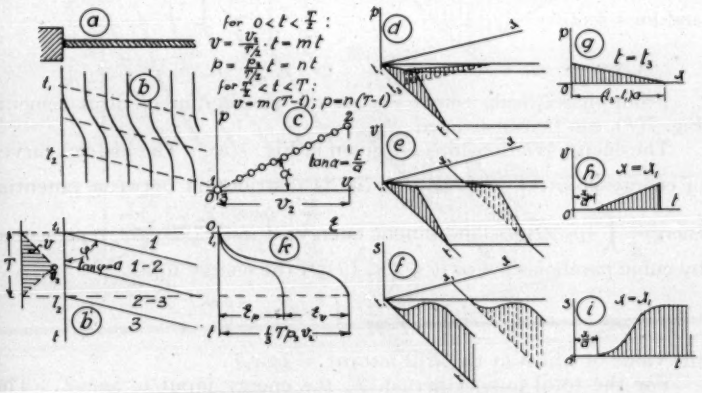

FIG. 7. Elastic impact in compression at variable velocity, bar of infinite length.

(*a*) Schematic arrangement.
(*b*) Displacement of cross sections.
(*b'*) Location diagram.
(*c*) Diagram of state.
(*d*) Stereogram of stress.
(*e*) Stereogram of velocity.
(*f*) Stereogram of displacement.
(*g*) Gradient diagram of stress, taken at instant t_3.
(*h*) History diagram of velocity, taken at cross sections x_1.
(*i*) History diagram of displacement of cross section x_1.
(*k*) History diagram of energy relations.

for $0 < t < (T/2)$:

$$v = \frac{v_2}{T/2}t = mt; \qquad p = \frac{p_2}{T/2}t = \frac{E}{a}mt = nt$$

and for $T/2 < t < T$:

$$v = m(T - t); \qquad p = n(T - t).$$

The stereograms of stress and of velocity, Figs. 7(*d*) and (*e*), as well as the gradient of stress, Fig. 7(*g*), and the history of velocity, Fig. 7(*h*), are constructed in the manner previously explained and do not need further elucidation. The displacement history diagram, Fig. 7(*i*), is composed of two parabolas with common tangent:
for $0 < t < (T/2)$:

$$s_0 = \int_0^t v dt = \frac{2v_2}{T} \int t dt = \frac{2v_2 t^2}{T2} = \frac{v_2}{T} t^2,$$

for $t = (T/2)$:

$$s_{T/2} = \frac{v_2 T}{4},$$

and for $t = T$:

$$s_T = \frac{v_2 T}{2}.$$

From these displacement curves the stereogram of displacement, Fig. 7(*f*), can be constructed.

The energy relationships are given in Fig. 7(*k*). The history curves of energy input, $\int_0^t pvdt$, as well as its distribution between potential energy: $\int_0^x (p_2/2E)dx$, and kinetic energy: $\int_0^x (\rho v^2/2)dx$ are represented by cubic parabolas. For $0 < t < (T/2)$ the energy input:

$$\int_0^t pvdt = \frac{2p_2}{T} \frac{2v_2}{T} \int_0^t t^2 dt = \frac{4p_2 v_2}{T^2} \frac{t^3}{3},$$

the value of which at the $T/2$ instant $= \frac{1}{6} p_2 v_2 T$.

For the total impact period, T, the energy input is $\frac{1}{3} p_2 v_2 T$. The energy distribution between potential and kinetic can be calculated in a similar manner.

Problem 4. Elastic Impact in Compression, Bar of Finite Length, with Free End, Duration of Impact Equal 2L/a (Fig. 8)

It is assumed that the bar length is finite, L, and that the duration of impact is $T = 2L/a$. It is seen in Fig. 8(*b*) and (*c*), that at the middle of the impact period, that is, at the $t_1 + L/a$ instant the entire length L of the bar is in a state 2, that is, has p_2 stress, and v_2 velocity. The far end of the bar, being free and unrestrained, cannot remain under stress; therefore the stress is reduced to zero (negative directrix drawn from point 2 to point 3, the intersection with the $p = 0$ line, that is, the abscissa axis) whereby the velocity is doubled: $v_3 = 2v_2$. This disturbance wave (change of state 2 to state 3) is reflected towards the impact end of the bar, where it arrives at the instant at which according to our assumption the impact ends. Thus, at the $t_1 + T$ instant the final state of the entire bar will be state 3, that is, $v_3 = 2v_2$; $p_3 = 0$.

The stereograms of stress, of velocity and of displacement are given in Fig. 8(*d*), (*e*), and (*f*).

The history of energy relations is given in Fig. 8(*g*). It is seen that until the middle of the impact period, $t_1 + L/a$, one half of the

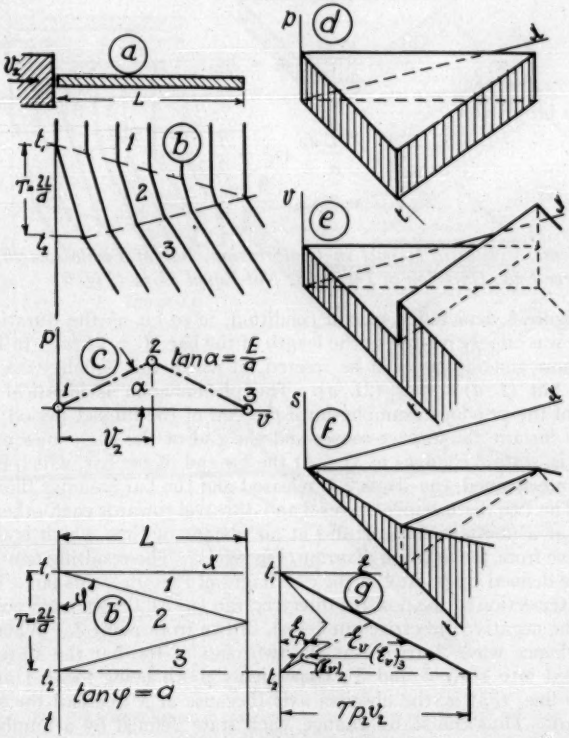

FIG. 8. Elastic impact in compression, bar of finite length, with free end; duration of impact $2L/a$.

(*a*) Schematic arrangement.
(*b*) Displacement of cross sections.
(*b'*) Location diagram.
(*c*) Diagram of state.
(*d*) Stereogram of stress.
(*e*) Stereogram of velocity.
(*f*) Stereogram of displacement.
(*g*) History of energy relations.

input energy appears as potential energy (stress energy), the other one half of the input energy appears as kinetic energy (velocity energy). Subsequently the stress energy diminishes, and entirely disappears at

the end of the impact period, $t_1 + T$, when the entire input energy appears as velocity energy of the bar. Input energy: $\mathcal{E} = Tp_2v_2$.

Final kinetic energy

$$\mathcal{E}_{v,f} = \frac{L\rho v_3^2}{2},$$

with

$$\frac{L}{a} = \frac{T}{2}; \qquad \rho a = \frac{E}{a}; \qquad v_3 = 2v_2; \qquad v_2 \frac{E}{a} = p_2;$$

it can be written:

$$\mathcal{E}_{v,f} = \frac{L}{a} \frac{a\rho}{2} 4v_2^2 = \frac{T}{2} \frac{4}{2} p_2 v_2$$

$$= Tp_2v_2.$$

Problem 5. Elastic Impact in Compression, Bar of Finite Length, with Free End, Duration of Impact is Not Equal 2L/a (Fig. 9)

Figure 8 depicted a special condition, in so far as the duration of input was closely related to the length of the bar: $T = 2L/a$. In Fig. 9 the more general case will be treated, in which this equality does not hold, but $(L/a) < T < (2L/a)$. The phenomenon is identical with that of the previous example, until the end of the impact period T, at which instant the impact ceases and the end of the bar comes to rest (that is, state 2 changes to 3). At the far end of the bar, which is free and unrestrained, the stress 2 is released and the bar assumes the state 3′. The two disturbance waves 3 and 3′ travel towards each other and meet at a point in the bar and at an instant of time which is determinable from the location diagram, Fig. 9(*b*′). The resulting new state will be defined by point 4 in the v–p diagram, Fig. 9(*c*), this point being the intersection of the positive directrix, tan $(+\alpha)$, drawn from point 3′ and the negative directrix, tan $(-\alpha)$, drawn from point 3. When the disturbance wave 4 arrives at the two ends of the bar the state 4 is changed into state 5 and 5′, respectively, both being located at the $p = 0$ line, that is, the abscissa axis (because at a free end the stress is zero). Thus the states change, each state defined by a number in the v–p diagram being valid for a domain of the t–x diagram, which is marked by the same number. The resulting stereograms are given in Fig. 9(*d*), (*e*), (*f*). It is seen that the bar does not attain one state over its total length, but, superimposed on its velocity imparted by the impact, it undergoes also variations of velocity and stress. The interchange of energies, kinetic and potential, is even more clearly shown in the energy diagram, Fig. 9(*g*). Until the termination of impact, that is, the end of the T period, the energy history is the same as in the previous example. From there on, there is a continuous interchange

between the energy of the middle portion of the bar (valid for the domains 4, 6, etc., of the t–x diagram) which is divided equally between

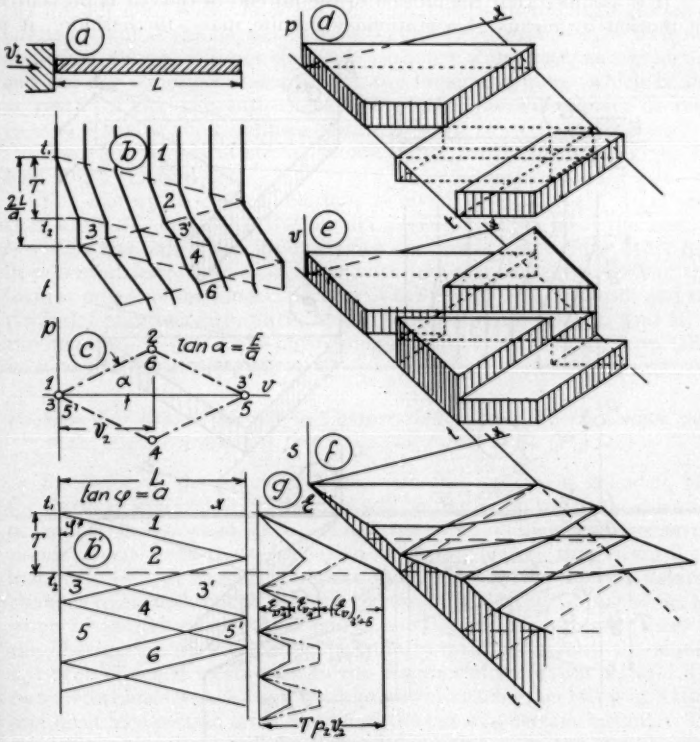

FIG. 9. Elastic impact in compression, bar of finite length, with free end; duration of impact less than $2L/a$.

(a) Schematic diagram.
(b) Displacement of cross section.
(b') Location diagram.
(c) Diagram of state.
(d) Stereogram of stress.
(e) Stereogram of velocity.
(f) Stereogram of displacement.
(g) History of energy relations.

kinetic and potential energy, and the energy of the end portions of the bar (domains 3, 3′, 5, 5′, etc.) which is of purely kinetic form (the stress being zero).

Problem 6. Elastic Impact in Compression, Bar of Finite Length, with Fixed End, Duration of Impact Equal $2L/a$ (Fig. 10)

It is assumed that the motion of the far end of the bar is prevented of motion by means of a stationary infinite mass; furthermore, it is

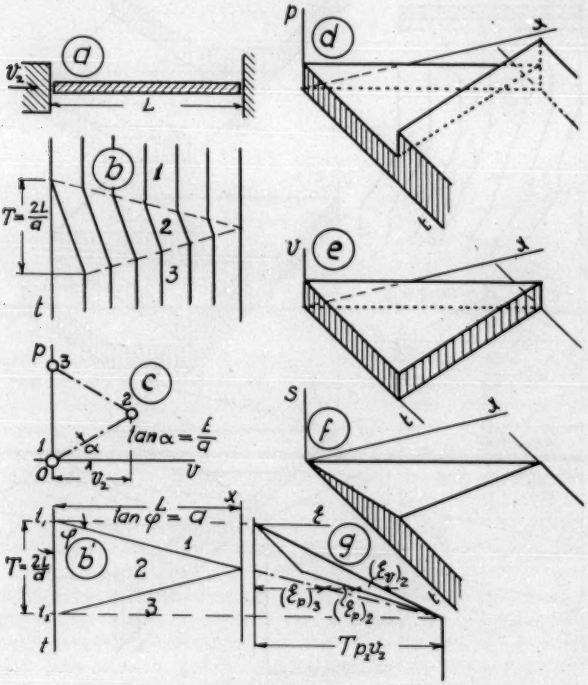

FIG. 10. Elastic impact in compression, bar of finite length, with fixed end; duration of impact $2L/a$.

(*a*) Schematic arrangement.
(*b*) Displacement of cross sections.
(*b'*) Location diagram.
(*c*) Diagram of state.
(*d*) Stereogram of stress.
(*e*) Stereogram of velocity.
(*f*) Stereogram of displacement.
(*g*) History of energy relations.

assumed that the duration of impact is $T = 2L/a$. It is seen in Fig. 10(*b*) and (*c*) that at the middle of the impact period, that is, at the $t_1 + L/a$ instant the entire length of the bar, L, is in the state 2, that is, it is under stress p_2, and is moving to the right with the velocity v_2.

Owing to the stoppage by the stationary infinite mass the state of this far end changes from 2 to 3, the latter being located at the intersection of the negative directrix tan $(-\alpha)$ (because the wave is moving *toward* the impact end) with the $v = 0$ line (that is, with the ordinate axis). On its arrival at the impact end the wave 3 ($p = p_3$; $v = v_3 = 0$) is not disturbed, that is, it is not changed into a new state, because also at this end the bar's motion is stopped by the impacting mass (which is also at rest). Thus, the entire length L of the bar will remain at rest, $(v = v_3 = 0)$, at the compressed state $p = p_3$.

The stereograms of stress, velocity and displacement are given by Fig. 10(d), (e), and (f).

The history of energy relations is given in Fig. 10(g). It is seen that until the middle of the impact period, that is, until the instant $t_1 + L/a$ one half of the input energy appears in kinetic, the other half in potential form, just as in a bar with free end, Fig. 8(g). From this instant onwards the kinetic portion of the energy will diminish, and the potential part increase, until, at the termination of impact, that is, at the instant $t_1 + 2L/a$, the entire energy will be in potential form (that is, $v_3 = 0$, kinetic energy is zero).

Problem 7. Elastic Impact in Compression, Bar of Finite Length, with Fixed End, Duration of Impact is Not Equal $2L/a$ (Fig. 11)

Similarly to the previous cases, with free end, Figs. 8 and 9, also for the fixed end condition the case will be treated in which the duration of impact is less than $2L/a$. This case, Fig. 11, is the same as the previous one, until the termination of impact period, that is, until the instant $t_1 + T$, at which the impact end of the bar comes to rest (state 2 changes to state 3, in the diagram of state, Fig. 11(c)). Meanwhile, the wave 2 has arrived at the far end of the bar and was stopped there by the obstruction of the stationary infinite mass. Thereby the state 2 has been changed to state 3′, in the diagram of state, Fig. 11(c). The two disturbance waves 3 and 3′ travel toward each other (see Fig. 11(b')) and meet at a certain cross section of the bar at a certain instant. The resulting new phase will be defined by point 4 in the v–p diagram Fig. 11(c), located at the intersection of the positive directrix tan $(+\alpha)$ drawn from the point 3′, and of the negative directrix tan $(-\alpha)$ drawn from the point 3. At its arrival at the two ends the wave 4 changes into states 5 and 5′ respectively, both being located on the $v = 0$ line, that is, on the p-axis. Thus the states change from domain to domain, as it can be easily followed in the location diagram Fig. 11(b'), and in the diagram of state, Fig. 11(c).

The stereograms of stress, of velocity, and of displacement are given in Fig. 11(d), (e), and (f), which can be easily constructed from Figs. 11(b) and (c).

The history of energy relations is given in Fig. 11(g). There is a similar analogy between Fig. 11(g) and 9(g), as was pointed out between Figs. 10(g) and 8(g).

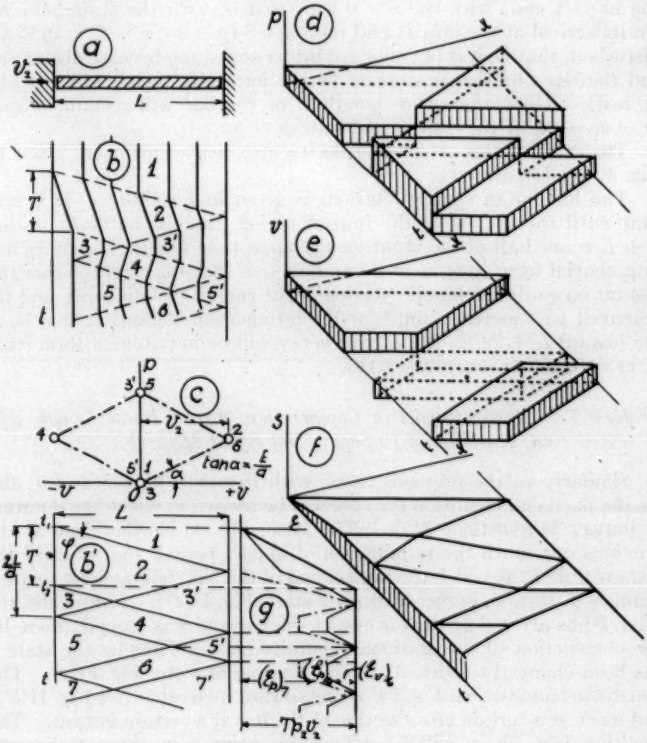

FIG. 11. Elastic impact in compression, bar of finite length, with fixed end; duration of impact less than $2L/a$.

(a) Schematic arrangement.
(b) Displacement of cross section.
(b') Location diagram.
(c) Diagram of state.
(d) Stereogram of stress.
(e) Stereogram of velocity.
(f) Stereogram of displacement.
(g) History of energy relations.

Elastic Impact in Compression, Bar of Finite Length, with Restrained End

In the previous examples, Figs. 8, 9, 10 and 11, the far end of the bar was considered either as entirely free, or completely fixed. Inter-

mediate conditions can be considered in which the motion of the bar end is restrained. The nature of the restraint may be friction, in which the resisting force is constant, and damping, in which the resisting force is a function of velocity. For both types of restraints various degrees can be considered, varying from entire free motion to completely fixed condition. Examples will be given for both types of restraint, and it will be assumed that the duration of impact is $2L/a$.

Problem 8. Elastic Impact in Compression, Bar of Finite Length, End Restrained by Friction (Fig. 12)

The condition of friction is analyzed in Fig. 12. The friction is considered to be a constant resisting force, corresponding to a unit stress r, which the stress existing at the friction-end of the bar must surpass before motion can result. Therefore, at the arrival of the disturbance wave 2 at the friction end, the state 2 will be changed to state 3 (in the diagram of state, Fig. 12(c)) situated at the intersection of the directrix tan $(-\alpha)$ drawn from point 2 with the r = const line. At the arrival of disturbance wave 3 at the impact end, the impact has *just* terminated, $p_4 = 0$, and the state of the bar changes to point 4 (because at the end of the period T the impact has terminated). On the arrival of the disturbance wave 4 at the friction end the state changes to 5; on the arrival of this wave at the impact end (which is now a free end, $p = 0$) the velocity will assume a negative value, point 6, which produces a negative stress, tension, point 7. But this negative stress is smaller than the stress r corresponding to the friction, hence no further motion at the friction end will take place, but henceforth residual energy will produce an interchange of fluctuating velocities and stresses, corresponding to points 6–7–8–9–etc., in the v–p diagram, Fig. 12(c). The stereograms of stress and of velocity are given in Fig. 12(d) and (e), which are self-explanatory.

Interest attaches to the total penetration of the friction end produced by the impact, that is, to the displacement of the friction end. This is determined by integrating the $v = f(t)$ line for the friction end: $s = \int v dt$, as it is shown in Fig. 12(f). It can be found also mathematically:

$$s = \frac{2L}{a}(v_3 + v_5).$$

The successive velocity values at the friction end form a decreasing arithmetic series, having a decrement of $2r(a/E)$, that is:

$$v_3 = 2v_2 - r\frac{a}{E}; \quad v_5 = 2v_2 = 3r\frac{a}{E}; \quad \cdots \quad v_{2n+1} = 2v_2 - (2n-1)r\frac{a}{E},$$

ending with the last member of positive sign.

The total penetration is:

$$s = \frac{2L}{a}(v_3 + v_5 + \cdots v_{2n+1}) = \frac{2L}{a}\left(2v_2 - nr\frac{a}{E}\right)n.$$

The history of energy relations is given in Fig. 12(*g*), showing that after the termination of impact there remains a residual energy in the

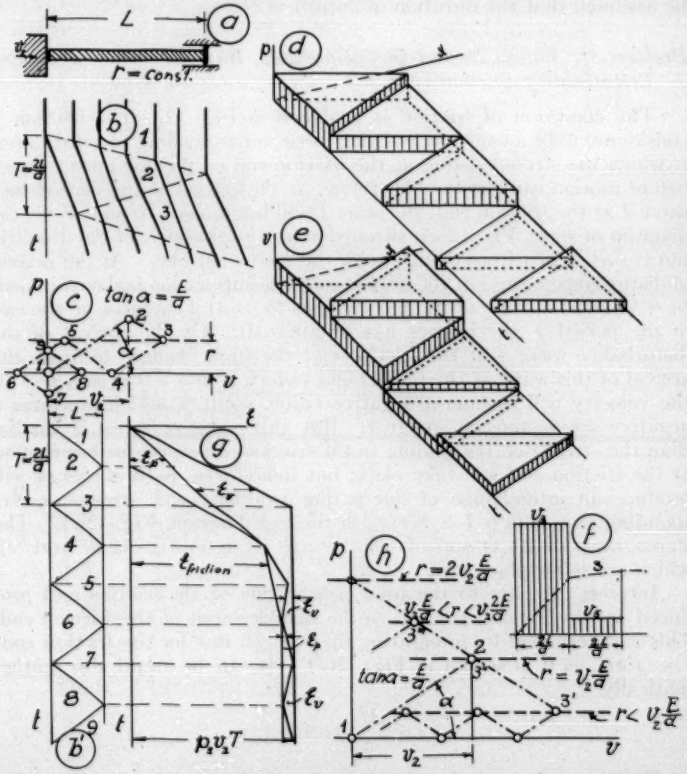

FIG. 12. Elastic impact in compression, bar of finite length, with end restrained by friction; duration of impact $2L/a$.

(*a*) Schematic arrangement.
(*b*) Displacement of cross sections.
(*b'*) Location diagram.
(*c*) Diagram of state.
(*d*) Stereogram of stress.
(*e*) Stereogram of velocity.
(*f*) Velocity and displacement of bar end.
(*g*) History of energy relations.
(*h*) Effect of varying friction on the p–v relations.

bar which constantly undergoes a transformation from kinetic to potential and *vice versa*. In particular cases, however, for which $(E/a)(v_2/r) = n$ is an integer number, there will remain no residual energy in the bar, but the total energy of impact will be consumed by the friction. Figure 12(h) shows the diagram of state for various relative magnitudes of the frictional stress r. Denoting $(E/a)(v_2/r) = n$ several cases can be distinguished:

If $n > 1$ there will be one or more than one penetration periods $2L/a$, the velocity of penetration decreasing in arithmetical progression;

if $n = 1$ there will be only one penetration period, and there will be no residual energy left in the bar after the termination of impact;

if $1 > n > \frac{1}{2}$ there will be one penetration period, and there will remain residual energy in the bar;

if $\frac{1}{2} \geqq n$ there will be no motion at the friction end, and the condition is equivalent to a fixed end.

Problem 9. Elastic Impact in Compression, Bar of Finite Length, End Restrained by Damping (Fig. 13)

The condition of damping is analyzed in Fig. 13. The damping force (or its value for unit area: the damping stress) is assumed to be proportional to the velocity. Also in this case, it is assumed that the duration of impact is $2L/a$.

Figure 13(b') represents the location diagram, and Fig. 13(c), the diagram of state. The damping stress is represented by a straight line OA having with the v-axis, a tan ρ slope for which: the damping stress $r = v \tan \rho$. The impact wave 2 arriving at the damped end is changed to state 3, being located at the intersection of the negative directrix drawn from point 2 with the damping line tan ρ. The successive states 4, 5, 6, 7 ... can be readily followed in the diagram of state. It will be realized that the tan ρ line takes the role of the r-line in the case of friction. The stereograms of stress and velocity are omitted in this case, though they could be easily constructed with the aid of the location diagram, Fig. 13(b') and the diagram of state Fig. 13(c').

Interest attaches to the penetration of the damped end. The penetration is the integral of the velocity values of the damped end:

$$s = \frac{2L}{a}(v_3 + v_5 + v_7 + \cdots),$$

as shown in Fig. 13(f). The velocities represent a decreasing infinite geometrical series, for which:

$$v_5 = v_3 \frac{1-A}{1+A}; \quad v_7 = v_3 \left(\frac{1-A}{1+A}\right)^2; \quad \cdots \quad v_{2n+1} = v_3 \left(\frac{1-A}{1+A}\right)^{n-1},$$

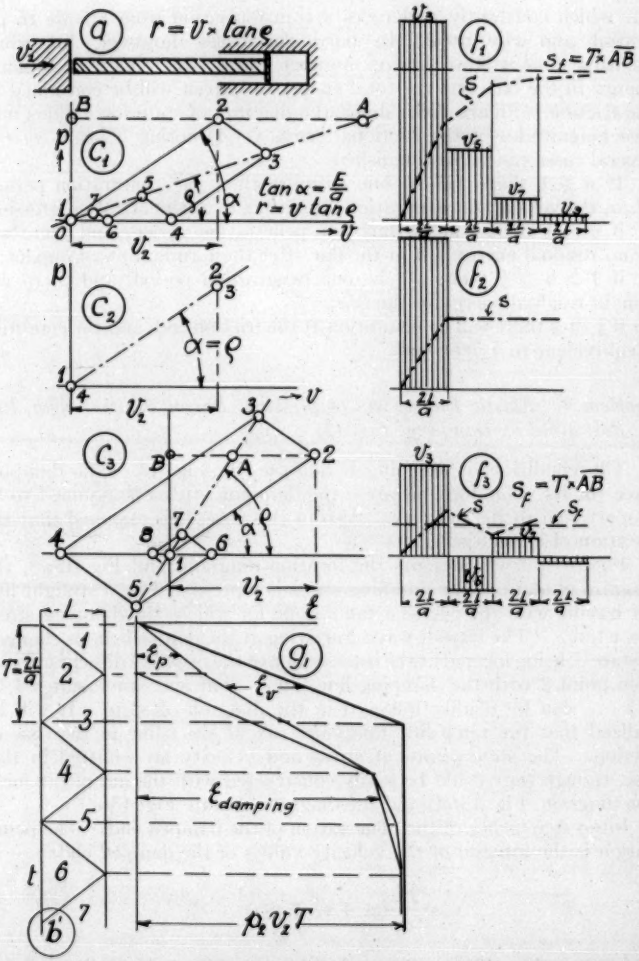

FIG. 13. Elastic impact in compression, bar of finite length, with end restrained by damping; duration of impact $2L/a$.

(a) Schematic arrangement.
(b) Location diagram.
(c_1) (c_2) (c_3) Diagrams of state for various degrees of damping.
(f_1) (f_2) (f_3) Velocity and displacement of bar end for various degrees of damping.
(g) History of energy relations.

in which

$$A = \frac{\tan \rho}{\tan \alpha},$$

and

$$v_3 = \frac{2v_2}{1 + A}$$

The sum of the above infinite series is:

$$v_3 + v_5 + v_7 + \cdots = \frac{1}{1 - \frac{1 - A}{1 + A}} \frac{2}{1 + A} v_2 = \frac{v_2}{A},$$

and therefore:

$$s = \frac{2L}{a} \frac{v_2}{A}.$$

The value

$$\frac{v_2}{A} = \frac{v_2 \tan \alpha}{\tan \rho} = v_A$$

is represented in the v–p diagram by the distance AB read in the v-scale as it can be readily seen by inspection. Point A is the intersection of the horizontal line drawn through point 2 with the tan ρ line.

The history diagram of velocity and of displacement for the damped end is shown in Fig. 13(f), and the history of energy input and distribution is given by Fig. 13(g).

According to the relative magnitude of the damping tan ρ and the wave factor E/a the progress of the phenomenon can be of different types:

(1) If $\frac{\tan \rho}{\tan \alpha} = \frac{r/v}{E/a} = A < 1$, that is, $\rho < \alpha$, then the velocity for the successive $2L/a$ periods will decrease in geometrical progression. This case was treated above, in connection with Fig. 13(c_1) and (f_1). This case is analogous to a periodic damping.

(2) If $A = 1$, that is, $\rho = \alpha$, then the bar will penetrate into the damping medium with the velocity v_2 (= impact velocity) during one $2L/a$ interval, after which the bar will come to rest in its total length (state 3) as shown in Fig. 13(c_2) and (f_2). This case is analogous to critical damping.

(3) If $A > 1$, that is, $\rho > \alpha$, then the motion of the bar will be in alternating directions with ever decreasing amplitude, as it is shown in Fig. 13(c_3) and (f_3). The total penetration of the bar into the damping medium will be the sum of these positive and negative velocities:

$$s = \frac{2L}{a} (v_3 + v_5 + v_7 + \cdots) = \frac{2L}{a} \overline{BA},$$

where it is to be noted that $v_3, v_7, \ldots$ are in the positive direction, while $v_5, v_9, \ldots$ are in the negative direction. The equivalent mean velocity is represented by $v_a = \overline{AB}$ read in the v-scale, where point A is found by a similar construction as explained above for Fig. 13(c), and with which:

$$s = \frac{2L}{a} v_a.$$

(Derivation is as follows:

$$v_3 = \frac{2v_2}{1+A}; \qquad v_5 = \frac{1-A}{1+A} v_3; \qquad v_7 = \left(\frac{1-A}{1+A}\right)^2 v_3;$$

$$v_9 = \left(\frac{1-A}{1+A}\right)^3 v_3; \qquad \cdots \qquad v_{2n+1} = \left(\frac{1-A}{1+A}\right)^{n-1} v_3.$$

It is to be noted that, $(1 - A)$ being negative, the fraction $\left(\frac{1-A}{1+A}\right)^i$ will be negative for odd values of i and positive for even values of i.

The sum is:

$$s = \frac{2L}{a} v_3 \frac{1}{1 - \frac{1-A}{1+A}} = \frac{2L}{a} v_3 \frac{1+A}{2A} = \frac{2L}{a} \frac{v_2}{A},$$

as in the previously treated case.)

Problm 10. Elastic Impact in Compression, Bar of Finite Length Having Discontinuities, End of Bar Free (Fig. 14)

If the bar is not of uniform cross section and material but it is composed of portions having different cross sections, or of materials of different elastic properties then at the cross sections at which the change is located the disturbance wave will also change from the previous state to a new state which change will be reflected in both directions from the cross section of discontinuity. Thus, a cross section of discontinuity arises, if on its two sides the wave factor FE/a is not equal. In this sense a free end is a cross section of discontinuity (because the cross-sectional area of the bar changes to zero, $FE/a = 0$) and a fixed end is a discontinuity (because the cross-sectional area of the bar changes to infinite, $FE/a = \infty$). In the following a treatment will be given to impact of bars having discontinuities between these limiting cases, that is, for which $0 < FE/a < \infty$.

As an illustration, a simple case will be analyzed, shown in Fig. 14(a), in which the bar is composed of three portions, AB, BC, and CD of different cross sections F_1, F_2 and F_3, and/or of different material prop-

erties E_1, E_2 and E_3 and a_1, a_2 and a_3, such that:

$$\left(\frac{FE}{a}\right)_{AB} : \left(\frac{FE}{a}\right)_{BC} : \left(\frac{FE}{a}\right)_{CD} = 1 : 0.75 : 0.50,$$

and

$$\frac{L_1}{a_1} = \frac{L_2}{a_2} = \frac{L_3}{a_3}.$$

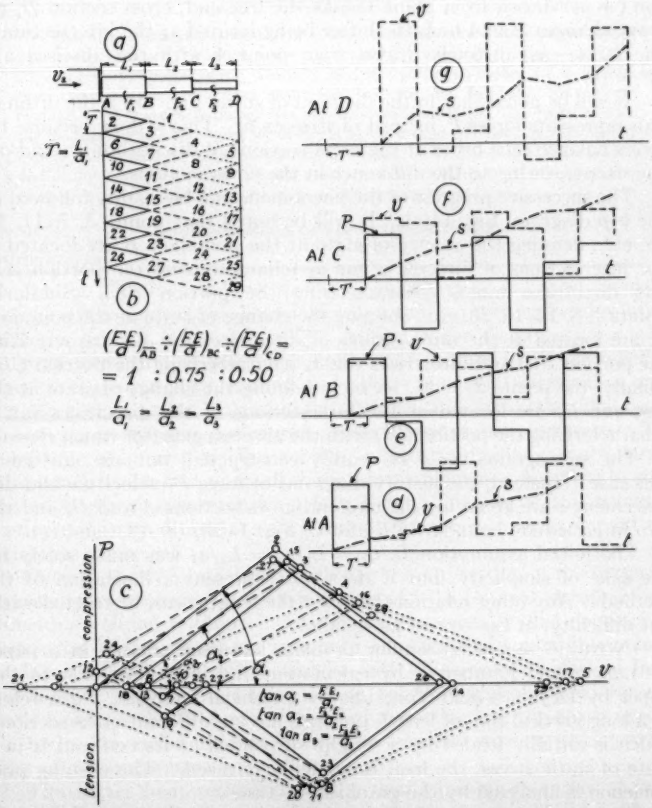

FIG. 14. Elastic impact in compression, bar of finite length having discontinuities, with free end; duration of impact L_1/a_1.

(*a*) Schematic arrangement.
(*b*) Location diagram.
(*c*) Diagram of state.
(*d*) (*e*) (*f*) (*g*) History diagrams of force, velocity, and displacement at the discontinuities.

It is assumed that the end A of this bar is subjected to an impact velocity v_2 lasting $T = L_1/a_1$ time. At the boundary B this state 2 is changed to state 3 (Fig. 14(c)) which is at the intersection of the negative directrix tan $(-\alpha_1)$ drawn from point 2 with the positive directrix tan $(+\alpha_2)$ drawn from point 1. When this wave 3 arrives at the boundary C the state changes to 4, being at the intersection of the negative directrix tan $(-\alpha_2)$ drawn from point 3 with the positive directrix tan $(+\alpha_3)$ drawn from point 1. At the free end, cross section D, the wave changes from 4 to 5, the latter being located at the intersection of the tan $(-\alpha_3)$ directrix drawn from point 4 with the abscissa axis $(P = 0)$.

It will be noted that in the diagram of state, Fig. 14(c), the ordinate axis represents forces P, instead of stresses p. This is done because the *forces* balance each other at the cross sections of discontinuity, and not the *stresses*, owing to the difference in the cross sections.

The successive progress of the phenomena can be readily followed on the v–p diagram, Fig. 14(c). It will be noted that points 3, 7, 11, 15, 19, etc., defining the change of state at the boundary B are located at the intersections of directrices tan α_1 (characterizing the portion AB) and directrices tan α_2 (characterizing the portion BC). Similarly, points 4, 8, 12, 16, 20, etc., defining the change of state at the boundary C, are located at the intersections of directrices tan α_2 (characterizing the portion BC) and directrices tan α_3 (characterizing the portion CD). Finally, the points 5, 9, 13, 17, etc., defining the change of state at the free end D, are located at the intersections of the directrices tan α_3 (characterizing the portion CD) with the abscissa axis (for which $P = 0$).

The stereograms could be readily constructed, but are omitted in this case. Instead, the history diagrams of force P, velocity v and displacement s are given for the two end-cross sections A and D, and the two intermediate boundaries B and C, Fig. 14(d), (e), (f), and (g).

The initial assumption $L_1/a_1 = L_2/a_2 = L_3/a_3$ was made solely for the sake of simplicity, but it does not represent a limitation of the method. Any other relations between the lengths can be treated without difficulty, at the cost of more labor.

(NOTE: A somewhat similar problem has been treated in a paper by Langer and Lamberger by calculation and in a discussion to this paper by DeJuhasz and Yorgiadis by graphical analysis. This refers to a long vertical rod, of length portions having different cross sections, which is initially loaded by a weight suspended at its end and is in a state of static stress; the load is suddenly released. The ensuing phenomenon is analyzed by the graphical method.)

The previous paper of the author treats elastic impacts of bars against other bars of various lengths, cross sections and restraint conditions. Therefore it is believed that the foregoing examples cover sufficiently the analysis of problems of elastic impact.

(To be continued in the August issue.)

VAPORIZATION COOLING OF LARGE ELECTRICAL MACHINES

BY

TH. DE KONING[1]

SYNOPSIS

This article describes a method of cooling as revolutionary as hydrogen cooling was in the twenties. A much wider applicability, considerable savings and other advantages are expected of it. The principles of vaporization cooling are so different from those customary for other media (air, hydrogen and fluid) that for a proper evaluation one must make oneself free from any preconceptions. The fundamentals, the far-reaching influence upon the design of machines and machine-sets, -stators and -rotors; the methods of supply of the cooling means, the conditioning of the machines and finally the influence of the cooling-means upon the insulation and other machine-parts (corrosion) will be discussed in this order in a condensed form.

1. FUNDAMENTALS OF VAPORIZATION COOLING

Introduction

For the "cooling" of large machines of all types—the word "ventilation" leads to undesirable associations—a much more universal solution than the present is possible. The cooling as the decisive factor must be considered first of all. The method of cooling to be discussed is simpler than hydrogen cooling and allows a natural integration with the machines coupled (for example, turbines and exciters). The result is a saving in housing, end shields, seals, bearings, couplings, etc. The auxiliary equipment for the cooling, which represents a much larger percentage of the cost of small than of large machines, has been in wide use on identical apparatus for a long time. The cost of this standard equipment is small and it can be used, moreover, in part, for all the machines of the set.

Over the present machines with the best utilization of the materials of construction one can expect: a saving of 5–15 per cent in copper- and punching-volume without increasing the current- or flux-densities; a somewhat better efficiency; improved simplicity and reliability; and a saving of 25–40 per cent in weight and 15 per cent in cost of large machines. Just as hydrogen cooling cuts the space needed for air-cooled units in half, so will vaporization cooling cut the space needed for hydrogen-cooled units in half. The overload capacity is as good as that of a transformer.

The better heat resistance of the iron laminations rather than of the windings is taken advantage of. No air vents, usually 4–12 per cent of the core length, are needed. Such a solid stator core is explosion- and corrosion-proof. The cooling has the advantages of hydrogen

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cooling (small windage losses and increased insulation life) but not the disadvantages (a large heavy shell, hydrogen purity and shaft-sealing equipment). Filling or exhausting the machines becomes a matter of minutes instead of hours. Careful supervision becomes unnecessary and the yearly outlay for lost hydrogen and scavenger gas can be saved. The machines are suitable for any size and environment and for any constant or variable speed.

Basic Principles

The essential parts of an electrical machine are the magnetic and winding materials. These are arranged in five concentric rings of iron, iron and copper, air, iron and copper, iron. Those adjoining the airgap generate about four fifths of the full load heat losses. The heat losses throughout the core length are the same, so for cores without air vents we have a two-dimensional heat field. The ring design is valuable for axial assembly and disassembly. All other parts but those mentioned are of secondary importance. Whether they are really needed or not has to be carefully looked into.

The air gap is the decisive place for the cooling and also for the supply of the cooling means. The relatively unprotected winding ends use up what remains of its cooling power. The heat resistance between the conductors and the cooling medium must be reduced to the utmost. The basic formula for the heat transmission is $1/U = \Sigma b/K + \Sigma 1/h$ with U = overall heat transmission coefficient, Σ = sum of the individual values, b = wall thickness in feet, K = heat conductivity coefficient, and h = heat transfer coefficient. K in Btu/sq. ft/hr/° F. is, for copper, 224; aluminum, 118; iron, 35; iron laminations (air gap) 25–15; laminations (air vents) 1–0.4; insulating materials 0.3–0.15; and trapped air in slots, 0.025. For the most favorable cooling speeds h in Btu/sq.ft/hr/°F. is, for air, 25–15; hydrogen, 40–25 for atmospheric pressures. The increase of the tooth temperature away from the air gap keeps the core at elevated temperature and makes the cooling of the stator-core outer circumference more effective. For thick cores and/or great winding heights, the air-gap cooling can be supplemented by means to be discussed later in detail.

The heat absorbed by air or hydrogen depends upon the temperature difference. About 20–30° C. (36–54° F.) maximum rise in gas temperature is permissible. Fans and circuit resistance can reduce this available temperature span up to 8° C. As the maximum temperature rise for the windings is 55° C. the temperature rise of the air will soon make it lose much of its effectivness. Moreover, an even air circulation cannot be guaranteed. The mean over-temperature is therefore taken at 0.7–0.8 instead of 0.5 of the maximum temperature rise. All this makes the temperature anywhere in the machine guesswork. Clear-cut conditions are essential and these can only be obtained with a cooling

medium of a temperature which remains constant during its heat absorption, of outstanding heat capacity, excellent heat-transfer coefficient, etc.

Constant Cooling-Means Temperature

The heat losses per unit of core length are the same, therefore the insulation stresses will be, too, with constant cooling-medium temperature. A sizeable decrease in cooling surface needed or in insulation strain is the result. In an evaporating medium the temperature remains constant until it is fully vaporized. As this only holds true at constant pressure we have a means of regulating the cooling temperature.

As the cooling is to be limited to the air gap (no dead corners, plugged passages, air vents) the cooling fluid is equally and fully utilized. With the high rotor surface speed, vapor and fluid form a finely divided mixture. As a housing is superfluous and the core explosion-proof, the end shields can be small, sturdy and light. Vacuum pressures are desirable because of the surface-friction. The vaporization temperature of the most effective fluids is around 70–100° C. For water at 0.8 psia. and a vaporization temperature of 34.2° C., 1 lb. has a volume of 418 cu. ft. and absorbs 962.5 Btu of heat. At 1.6 psia., and a temperature of 47.3° C., 1 lb. has a volume of 214 cu. ft. and absorbs 962.5 Btu.

Now 1 lb. of air, about 13.6 cu.ft., absorbs about 12.9 Btu with a temperature increase of 30° C. The heat-transfer coefficient of evaporating liquids is about 50 times that of gases. Even with a cooling-surface reduction the whole temperature difference, instead of only part, can be used for cooling the windings. As will be proven later in this paper in detail, water and steam, when properly applied are at least as good an insulating means as air or hydrogen. In a closed cycle-cooled machine the fundamental requirements can be easily fulfilled.

Closed Cycle Cooling

Closed cycle cooling is desirable with fluids to be kept at high purity. As only small quantities are required, small diameter piping for the fluid and a highly utilized vapor space of ring volume are sufficient. Most of the cooling is done in the air gap. The end rings and end shields fit closely over the winding ends. Even over-dimensioned condenser(s) will be much smaller than the cooler for hydrogen-cooled machines. The heat-transfer coefficient of cooling water is about 400–1200; that of vaporizing water or condensing steam, 2000 and more; air, 15–25; hydrogen, 25–50.

During condensation, air and all other undesirables are being immediately removed (compare hydrogen cooling); moreover, a fluid can be much better cleaned than a gas. Dust from any source (atmosphere, brushes, collectors, commutators) is removed as sludge by any fluid

filter. With a well-conducted vapor stream, the interior of the machine becomes progressively cleaner. No scavengers are needed, neither long drying-out periods or large air filters. Fans are not needed. Any reason for not having the exciters in the main housing disappears and one gets rid of one shaft seal.

The winding ends can be cooled by the vapor-mist mixture, leaving the air gap at high speed and small water content. The steam will become slightly superheated which keeps the winding ends dry, end shields and end rings above air gap- and certainly above condenser-temperature. Stator core and bearings are naturally above vaporization temperature. When out of service the outer air can be let in through a filter. This prevents water absorption of the windings even then.

A Chemically Inert Cooling Medium

The explosion danger of hydrogen requires a complicated auxiliary equipment and highly skilled attendants, while with an evaporating fluid the standard equipment is easily maintained. The vacuum pump prevents gas accumulations. Generator fires are unlikely with hydrogen, impossible with water-vapor cooling. Neither ozone nor nitrous oxides, both dangerous to the insulation, can be found in hydrogen or vaporization-cooled machines. Corona does not cause damage. As 1 lb. of water requires 5720 Btu, its dissociation in hydrogen and oxygen at low pressures and temperatures is unlikely. It is to be expected that the insulation will behave at least as well in vacuum steam as in hydrogen. This will be the case for short circuits, too.

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Principles of Cooling-Means Supply

Every surface unit must get exactly the quantity required for its needs. The fluid stream must therefore be subdivided and broken up by rapid motion in the air gap, the stream hitting a hard surface, atomizing nozzles, over-temperature and -pressure or other means.

The smaller the fluid drops the larger their surface and the easier it is for the vapor to free itself. Absence of air and clean surfaces permit heat-transfer coefficients of 2000 and more. Even an over supply of fluid is no objection in a well-guided vapor stream flowing towards the condenser. There are no vents in which it can accumulate. A collection of fluid in the rotor is impossible (centrifugal force), and is practically impossible in the stator core. The teeth tips are coolest, the teeth roots hottest. Any fluid penetrating between teeth and coils cannot get any further because of the vapor it creates and is quickly dissolved. The same holds true for fluid trying to penetrate the insulation. The lowest temperature in the machine (except for the condenser) is the air gap. Superheating the steam before it is condensed is an

insurance against too much fluid being supplied. The heat absorption of vapor is about twice that of air; also, with too little water the temperature rises rapidly.

Principles of Cooling-Means Control

The cooling of vaporization-cooled machines is independent of speed (speed range), outside temperature and atmospheric pressure. Only those fluid quantities have to be supplied which are needed to remove the heat created by the losses. Superfluous and undesirable cooling at no load or small loads is done away with. The heat movements can be much better controlled and are therefore smaller and less abrupt. With a two-dimensional heat field exact calculations are possible, the basic condition for a useful temperature control. With all losses to be removed by vaporization cooling a 50,000 kva machine with 2 per cent losses needs at full-load, 400 gal. of water, instead of 40 million cu. ft. of air every hour. With 7 ft. per sec. water speed, the interior diameter of the main supply tube is only $\frac{3}{8}$ in.

A small regulating valve or pump is sufficient, therefore, to adjust the supply to the momentary demand. A thermostat in the vapor flow just before it reaches the condenser can take care of the regulation. Heavy overloads are taken care of by increasing the fluid supply (practically useless with air), if so desired aided by a better vacuum and increased condenser-water supply. Rapid load changes can produce heat strains and relative movements, for example, of the insulation in the slots. With slow movements the weakest material has time to adjust itself, tears and other surface damages can be prevented. Insulation breakdowns are often due or aggravated by such an initiation. With a sensitive and accurate temperature control these strains can be dampened and decreased in magnitude.

2. ELECTRICAL MACHINES

In brief, the derived advantages are: the heat losses are removed as evenly as generated without an increase in cooling-means temperature; the vaporization-cooled surfaces can be limited to the air gap; the cores are without air vents and the stator-core circumference as the outside of the machine is naturally cooled; the cooling fluid is only needed in small quantities; it has when evaporating an excellent heat-absorption and heat-transfer coefficient, a small surface friction, is explosion proof, non-inflammable, does not penetrate the winding surfaces and removes any kind of dust and undesirable substances fully; the cooling fluid is supplied according to the momentary need; fans and gas filters become superfluous; the cooler becomes considerably smaller; auxiliary apparatus is hardly needed and is only of the simplest and fully developed kind. All this indicates that a far-reaching simplification in machine construction must be possible.

Fluid Supply and Vapor Flow

The cooling fluid can be supplied through small radial channels, in the stator core, from outer circumference to air gap. The smooth air-gap surfaces (unbroken through air vents) prevent water accumulations and make the nearly saturated vapor flow with increasing speed towards the winding ends. This reversal of the usual direction of flow and the increasing vapor speed are of the greatest importance as will be shown later. For the 50,000 Kva. machine with 2 per cent losses and 25 points of supply, 7 ft./sec. water speed in the connecting tubes and 20 ft./sec. in the hair tubes in the core, interior diameters of $\frac{1}{8}$ and 5/64 in. are needed. The hair tubes equalize the water supply independent of supply tube length and are so small that they can easily be led through the teeth to the air gap. Any number of supply points can be chosen. One is free in the spacing. The openings themselves are so small that they will hardly be visible. The number of supply points used at any time can be made dependent upon the quantity of fluid needed.

An equalized distribution of the cooling medium over the air-gap surfaces independent of the quantity of heat to be removed is desirable. The volume of the vaporizing fluid to be supplied to the air gap will vary widely dependent upon the load and other factors. Now the shape, wetted surface and droplet size of the fluid coming out of an opening are influenced more or less by the fluid speed. What is needed is a method of supply similar to that used for the better fuel-injection systems. It injects carefully measured oil quantities in accordance with the load at accurately predetermined time intervals independent of the motor speed to the individual cylinders. A water-injection system built to less exacting specifications can be used. One is much freer in the injection duration and instead of one hair tube a whole row can be supplied. Moreover, the timing between the rows does not have to be so accurate as between cylinders. As a result the number of supply points can be taken at will.

The vapor speed midway between the exhaust rings (usually the core sides) will be zero. The flow resistance is therefore one third of the one of a constant vapor flow of exhaust ring velocity. Because of the rotor-surface speed of 300 mph. and more, an axial component of the vapor speed of considerable magnitude hardly increases the surface friction at the rotor side. Also, fairly high exit velocities can be used. From an aerodynamic point of view vaporization cooling, compared with air- or hydrogen-cooling, is outstanding.

Figure 1 is a sketch for a vaporization-cooled machine. The closed housing contains from right to left the fluid supply tubes, stator and rotor, the thermostatic regulator and the condenser cooling coil. The condensed vapor collects in the lower half of the condenser and passes through a cleaning filter in the refillable water container at atmospheric pressure. In service the vacuum in the machine sucks the water by

way of the thermostatic regulator and the supply tubes into the machine in the quantity needed for the cooling. The regulator is operated by the temperature of the vapor flowing in the condenser. The air collects in the upper part of the condenser and is continuously removed.

To put the machine in service, the hand control closes the air-inlet valve and the electric circuit. This circuit starts the machine and the pumping set automatically. As the vacuum space is small the pump will create the necessary vacuum from atmospheric pressure in no time. This is in marked contrast to preparing a machine for hydrogen cooling. When shutting down the machine the hand control opens the electric circuits and the valve which lets dry air in the machine. It is all very easy for the attendant.

The apparatus for the condensation and fluid supply consists also of pumps, squirrel-cage motor, contactor, fluid valve and fluid filter, all mass-production articles. As only small sizes are needed, the equipment can be build in or upon the machine.

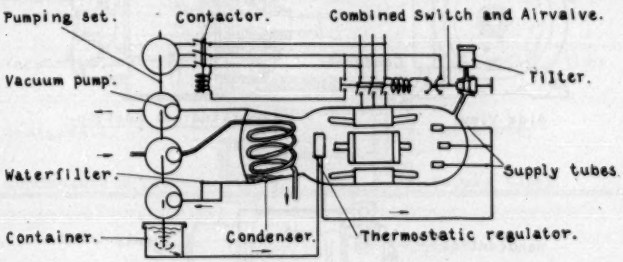

FIG. 1. Sketch of the cooling machine in principle.

Electrical Machine and Auxiliary Equipment in One Unit

The auxiliary apparatus needed is the same as for the simplest surface condensers. For a 200-Kva motor with 92 per cent efficiency, four fifths of the losses to be removed by vaporization, one fifth by natural cooling, only ½ gal. of water is needed at full load every hour. As the condenser can be placed between stator end windings and outgoing shaft the machine dimensions need not be increased even when the condenser is designed for large overload capacity, shaft sealing and bearing cooling. Figure 2 shows such a vaporization-cooled machine in side view, front view and longitudinal section.

The vapor blast increases in sealing ability with the load. The condensate passes an exchangeable filter which removes carbon dust, dust, oil, etc. and flows through the pump in the supply reservoir. At atmospheric pressure this reservoir can be refilled at any time. If cast in the lower end shield the water in the supply tubing will automatically

flow back when the air valve is opened. Excepting the thermostat placed between rotor and condenser, all apparatus can be mounted on the outside of the machine. For small machines a combined air- and condensate-pump and a valve for the cooling water may be sufficient. If the natural pressure difference (fluid supply dependent upon vacuum pressure) must be increased, a small pressure pump can be useful. At the place the machine is going to be used only electrical and water connections have to be made.

Electrical Machine with Air-Cooled Condenser

Where water is objected to for the condenser cooling or the needed quantities of cooling water are not available, air cooling can be used.

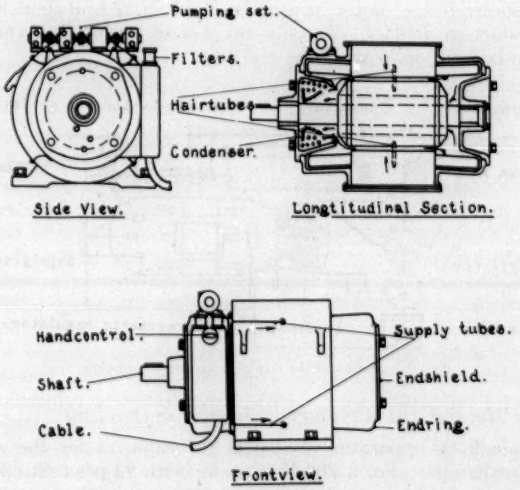

FIG. 2. Self-contained water-cooled machine.

As large vapor velocities are permissible, the vacuum-steam pipe can be small. The condenser can be placed in the most favorable position, especially since with modern welding airtightness can be assured. A ventilator, if so desired, in an aerodynamically designed air duct that turns in wind direction can be used and finned tubing (see Fig. 3). The tubing will be under external pressure (no inter-crystalline corrosion.) Even for the largest machines little water is needed for the vaporization cycle. With water cooling this quantity is maintained or even increased by means of entrained water and because of the fact that the water temperature is below the air temperature. This is not

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the case with air-cooled machines, so the water level has to be checked every three months or so (vapor in the air removed by the vacuum pump).

Because of the thickness of the stator core the sun can burn upon vaporization-cooled machines without increasing the burden upon the cooling. This is not so with air- or hydrogen-cooled machines. It is an additional safeguard in preventing condensation in the end rings or end shields. The air condenser being small in size, its outer surface cannot absorb much heat either.

When using air cooling the water cooling of the stator core (to be discussed later) becomes a closed circuit independent of or interconnected with the vaporization cooling. An interconnection has the advantage of decreasing the water reserve needed and also of allowing

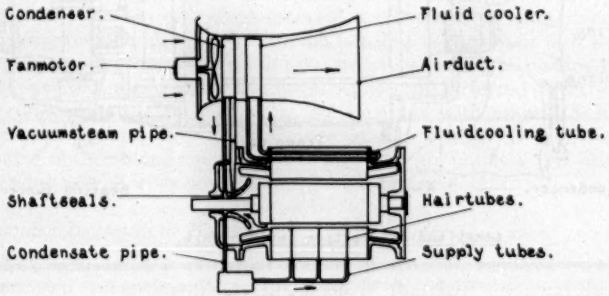


FIG. 3. Air-cooled vaporization machine.

the water for the vaporization cooling to be tapped at the highest temperature. Furthermore the condenser and the cooler can be put behind each other in the air-cooling circuit. Only one ventilation fan and air duct are needed in that case. The total air resistance will not be much increased.

The vacuum seal for the outgoing shaft of air-cooled machines can be like the one for machines with a water-cooled condenser around the shaft. The vapor stream will be directed towards the bearing and the vapor intakes arranged in a circle before it. The condensed vapor out of the condenser forms a ring seal between atmosphere and machine vacuum. Afterwards it is pumped in the water container from where it flows regulated by the thermostat to the tubes opening in the machine-airgap.

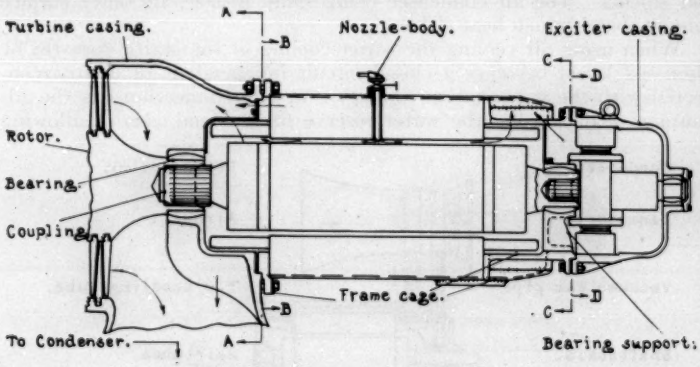
3. ELECTRICAL MACHINES AND MACHINE-SETS

The larger sizes of electrical machines usually form a unit with driving or driven machines, for example, in speaking of frequency con-

verters or turbo-generators, the complete equipment including exciters is meant. With such expensive sets it is desirable to know whether any single part, as end shields, bearings, couplings, etc., is really needed.

A Vapor Space in Common to Two or More Machines

As vaporization cooling and a satisfactory vapor guidance remove carbon dust fully, all electrical machines including exciters can have



Longitudinal Section through Unit.

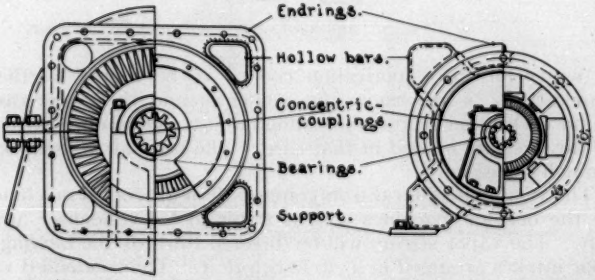


FIG. 4. Turbo-generator unit.

a vapor space in common. Contrary to hydrogen cooling, for example, opening a machine for a brush renewal means not any or only a short intermission, as the air pump which can be assisted by an ejector has the vacuum back to normal in no time. The necessary humidity for the brushes is always maintained. Water vapor is an excellent insulator.

The advantages of a vapor space in common are: no shaft seals, one closed housing suffices, only one condenser and its set of pumps are needed for the whole housing, the over-all length decreases. As exciter losses are at the most a couple of per cent of the main machine losses an enlargement of the condenser or pump-sizes is superfluous. The one part needed for each machine in the housing is a thermostatically controlled regulating valve, all parts for the condensation are in common (see Fig. 4).

The vacuum pressure of condensing steam turbines is suitable for electrical machines, also a vapor space in common can be used. The two remaining shaft seals disappear and the ideal condition is attained. Neither the turbine condenser nor its auxiliary equipment will notice the 1 per cent load increase. The time out is not influenced as one machine out of commission means that the whole set is.

Contrary to air- or hydrogen-cooled machines there is no objection to having the bearings in the common housing as the vapor flow out of the air gap and proper design will prevent any water in the bearing oil or oil vapor from getting at the windings. They will be forced directly into the condenser. As the oil enters the bearings with about 15–30 lb. over pressure and only a 30° C. rise in temperature is permissible, foaming of the oil and the creation of oil vapor are unlikely. A bearing functions as well in vacuum as under high pressure.

Combined Intermediate Bearings and Couplings

Any bearing is a potential source of trouble, requires excellent supervision, a continuous stream of oil of the right temperature and quality and mostly a cooling system. The bearings must be very carefully adjusted and every time the machine is taken apart the positive alignment and functioning must be accurately checked.

The fewer the bearings the better. The bearing size does not matter as long as the dimensions are in accordance with the load. Now the shaft in the bearings is bigger than in the shaft ends. Furthermore, the rotor of an electrical machine can be removed in axial direction. This is not possible with turbine rotors of normal construction.

The shaft in the bearing can be bored out quite a bit without losing its strength, a cubic function of the diameter. With teeth on the inside of the boring, the shaft to be coupled with teeth on the outside, both fitted together with the fine tolerances of high-grade gearing, only one bearing is needed and no additional coupling. With a sliding- or push-fit the necessary clearance is small compared to a running fit (bearing clearance); moreover, the clearances are dependent upon the diameter. Even if they act as solid couplings at full speed this will not interfere with the assembly, disassembly and warming up. Only for those, axial motion is desired. The turbine shaft is short and better suited for direct support. The long rotor shaft can be removed axially. The

teeth tips at the ends can be shaped for easy assembly and disassembly (see Fig. 4).

A check-up for proper alignment is easy. Removal and even exchange of the rotor of the electrical machine can cause no damage to the sensitive bearing surfaces. No bearing-adjustment or even a check-up is needed. There is no wear on the coupling-teeth. One bearing fixes a rotor axially. Overall length and engine room space for the removal of the main electrical rotor are saved.

Spigot Type Exciter with Plug Contacts

The larger synchronous machines have their own exciter mounted on the shaft between one of the main-bearings and a third bearing with its stator on its own pedestal. With overhanging exciter rotors the commutation is easily disturbed. With the bearing and coupling construction mentioned the exciter can be fastened, instead of an end shield, spigot-fashion on the stator end ring (see Fig. 4).

The flange insures excellent centering and support. With the small contact pitch circle even a slight angle between the shafts is permissible. The commutator being near its own bearing is unlikely to be affected. An emergency shaft seal and connecting valves can be used to facilitate maintaining the vacuum when an exciter must be opened for a brush inspection or renewal. For the current leads, disconnecting switch contacts or plug contacts can be used. The replacement of such an exciter only takes the machine out of service for a few minutes. Pilot exciters can use the same construction. The short main rotor length and the self contained units of construction are further advantages.

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4. STATOR AND ROTOR

Machines for vaporization cooling are fully self contained, do not require openings in the foundation and are, because of the vacuum, as noiseless as hydrogen-cooled machines. The end shields fit closely over the winding ends; vapor space and machine dimensions are small. The ventless stator core becomes the outside of the machine.

The Nozzle Bodies in the Stator Core

The air gap is especially suitable for applying the cooling fluid, as the windings are well protected in the cores on all sides. The thin supply tubes contain but little fluid. As fluids are incompressible there is no time lag between control valve and supply openings.

The nozzle bodies can be led through and sealed in radial channels in selected groups of laminations. For inspection, a tube can be sealed in the core with the nozzle body fitting closely in it (see Fig. 4). With a copper connecting tube of sufficient length it can be taken out at any time, inspected, adjusted, cleaned or even exchanged and put back again. Nothing has to be disconnected. The removal of 1 body out of 25, for

instance, hardly influences the cooling at all. The vacuum will not change much even if the opening is not plugged. A cleaning of air-cooled machines takes the machine out of service for a long period of time and still the proper distribution may not be attained or a constriction gotten at.

The direction and shape of the water jets can be according to requirements. The water droplets will be thrown against the rotor and move over it cooling the surface at the same time until they have attained about rotor speed. What remains of the water droplets is thrown against the stator laminations and cools these and the windings.

The Cooling of the Stator Core

With thick cores and high silicon laminations and where a predetermined maximum outer temperature is desired or a controlled temperature at the bottom of the winding slots, fluid-cooled holes in the length of the stator offer a very acceptable solution. High core temperature and low winding temperatures are basically impossible with air- or hydrogen-cooled machines. Insulating the hole walls prevents leakage or rusting. Non-conductive plastic tubing (eddy currents) can be bent or welded and made to form a good contact with the punched holes.

The excellent heat absorption and heat transfer of liquids makes only small diameter holes necessary. Furthermore, a much higher surface temperature can be allowed as for the windings. High initial fluid temperatures can be used. Used bearing oil or used cooling water from the condenser can be taken. As about a third of the losses can be removed this way the condenser size and the quantity of cooling and vaporization water can be reduced by the same amount. This is not possible with air- or hydrogen-cooled machines. The latent heat of the stator is to be kept high at all times so the fluid content of the holes must be small. Return bends are useful because of the slight conductivity of the water and to keep the heat field as two-dimensional as possible (see Fig. 3).

The solid laminated stator core can be enclosed in a frame cage (like for a squirrel-cage rotor) consisting of end rings and longitudinal bars (hollow for strength and vapor guidance). End rings and end shields can be externally or internally insulated, if so desired, if condensation is feared in them. As the laminated core is somewhat elastic in axial direction the balancing of expansion coefficients and temperatures of conductors and bars will prevent insulation damages (see Fig. 4).

The Cooling of the Rotor- (and Stator-) Winding Ends

The stator-core end windings are cooled by the vapor coming out of the air gap passing centrifugally outward through them on its way to the condenser. To facilitate this flow and to prevent the short sides

of the rectangular cross-section of the winding ends from getting more then their share of the wet vapor, the winding ends can be given a drop-shape or hooded.

For the rotor coils at each rotor-end the end windings can be cooled by the fluid spray out of tubes with their openings between rotor shaft and end windings. The naked innermost turns are cooled at their flat side by the spray; the sides of the staples of turns are cooled with decreasing intensity towards the rotor end caps. Thus the cooling effect gradually decreases toward the rotor circumference. This progression is contrary to the one of the embedded length of the coils. The rotor-surface cooling can never be so effective because of the slot insulation and the keys. Furthermore, the vapor flowing out of the air-gap ends will move radially outward as soon as possible so the rotor end caps will be poorly cooled. All these factors together make the mean-temperature gradient in radial direction in the coils quite small in comparison to those in air- or hydrogen-cooled machines.

5. THE VAPORIZATION FLUID AND THE WINDINGS

Introduction

The rules for applying vaporization cooling are different from those applying to air cooling and hydrogen cooling. The quantity needed only depends upon the heat losses to be removed and is independent of temperatures and temperature differential of cooling substance and cooling surfaces. With the latent heat of evaporation the total heat absorption between two practical temperatures is the same. With constant fluid regulator setting the pressure difference between supply and vacuum determines the flow. An instantaneous fluid reduction as well as a surface-temperature rise is the result of a vacuum breakdown.

If the vaporization temperature (vacuum pressure) increases, the temperature difference for the removal of the heat out of the windings decreases. Temperature gradients become less and maximum temperatures increase. This makes it even more difficult for the fluid to penetrate and damage the insulation. The exposed winding ends are cooled by nearly dry clean vapor instead of the wettest and dirtiest gases as with air cooling. No surface damage can be caused by creepage. The disruptive strength of water is 56.5 kV. compared to 25 kV. for atmospheric air. The resistance of water is about 4×10^{-8} ohms per cu. mm., the one of petroleum 3×10^{-13}. However in the mist stage this is of little importance and, in the superheated vapor-stage, of no importance at all. After dry air has been valved in a totally enclosed machine no water can condense or leak on the windings. The filter will keep the breathing air dry, too. Furthermore, there is a lot of latent heat in cores and windings which can be used for insulation drying and the vaporization fluid supply can be cut off when desired.

In air- or hydrogen-cooled machines water on the windings can

cause damage because of a through-wetting. A superficial judgment will attribute the same to vaporization-cooled machines. However, what are the facts? Take the insulation resistance. It is used as a criterion to judge whether the insulation is in satisfactory condition. Also a resistance-temperature curve taken of hygroscopic paper fiber will be instructive (see Fig. 5). It shows a falling-off with increasing temperature to a dangerous low at about 85° C. The maximum remains about constant at 115–130° C. The explanation is that the increased vapor tension frees absorbed water and forms conducting paths. Only around the vaporization temperature of 100° C. can this moisture be expelled. In vacuum machines the vaporization temperature (at 1 lb. 100° F.) is near the lowest temperature the machine will assume in or out of service. This makes water absorption next to impossible. The insulation remains in top condition over the entire temperature range. This fully justifies a smaller insulation thickness. The electrical insulation value rapidly decreases with an increase in

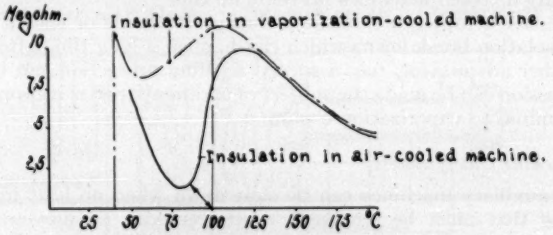

FIG. 5. Resistance-temperature curves for hygroscopic insulation.

thickness (mica: 0.1 mm., 150 kV/mm.; 1mm., 50 kV/mm.). This proves the value of a thin insulation for high-tension windings for a high power rating and long life of the machine, as the heat resistance is proportional to the insulation thickness.

Diffusion of Water and Vapor in the Insulation

The regulation of the vaporization fluid supply according to need keeps the insulation surface temperature practically constant and at least at vaporization-pressure temperature. The temperature increases gradually towards the conductor so diffusion of water in the insulation is impossible and furthermore, steam is even a better insulator than air. The electrical machine out of service is filled with dry air or inert gas of atmospheric pressure.

The pores (holes) in the insulation can be divided into those connecting to the outside and fully closed pores. The last need not be considered here especially as the percentage of the insulation volume taken up by non-solids is negligible. All pores have in common that they are of

microscopic size in undamaged insulation. The smaller their size the less damage equalizing vapor- or gas-currents, etc., can cause. The connecting pores will be filled with air, and there is no reason to assume that this air will be more than saturated with steam according to temperature and pressure. When letting dry air in the machine when it is taken out of service, part of the pores and connecting channels will be closed by the pressure. The other ones will fill themselves with dry hot air, thus precluding an increase in moisture content.

In air-cooled machines (daily temperature cycles, small load, moisture laden air) the pores of the insulation can gradually suck themselves full of water by condensation at the inside and so on. To dry the insulation (temperature about 80–100° C.) a volume of vapor thousands of times that of the water is created. The vapor flow or vapor pressure (clogging) can therefore seriously weaken the insulation and initiate insulation breakdowns. Dirt getting in the insulation can do much damage, too. The absolutely clean controlled vacuum atmosphere in vaporization-cooled machines prevents all this.

Excessive temperatures created during overloads or shorts initiate most insulation breakdowns which can happen a long time afterwards. With other advantages, too, a special winding protection can be used. Its discussion can be made the subject of another paper as its application is not limited to vaporization cooling.

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The Machine Out of Service

The auxiliary machines can be shut down when no heat losses are produced that must be removed or intercepted. To prevent water- or moisture-laden air from creeping through pumps, seals, etc., an easier way is to be provided to attain atmospheric pressure (see Fig. 1). The dry air admitted through a valve and a filter absorbs all the vapor and any water particles left, while assuming the mean machine temperature.

As the condenser is still for some time the coldest part of the machine, the air will give off most of its moisture there. Under exacting circumstances the auxiliary machines can be kept running for a while (time element). The winding surfaces will assume the mean temperature and become hotter than in service. This assures a thorough drying out, as no vaporization fluid is supplied any more. By the rate of temperature increase of the vapor flowing in the condenser an experienced attendant can judge closely how dry the machine is. By cutting of the vaporization water supply for the time needed for the experiment this is possible whenever desired with the machine in service. A connection to the atmosphere through a filter keeps a closed cycle cooled machine dry independent of time and atmospheric changes when out of service.

Under unusual circumstances a trickle of water in the condenser coil can fix a coldspot. The air volume is only a fraction of that in

gas-cooled machines relative to the exposed winding surfaces. In the latter, 65 per cent saturation must be counted upon with higher temperatures.

It is further to be noted that under normal operating conditions the fluid level of the atmospheric water container remains constant whatever the load. The fluid contents of the closed cooling system can be small so the slightest leak outward in the atmosphere or a fluid accumulation in the machine will soon change the short-time position of the float in the water container. This float can actuate an alarm or take all measures desired. Vaporization cooling makes for simplicity of the means employed.

The Hair Tubes In or Out of Service

If any break in the supply tubing occurs it must be outside the core. With hair tubes even thin walls have great strength. An automatic

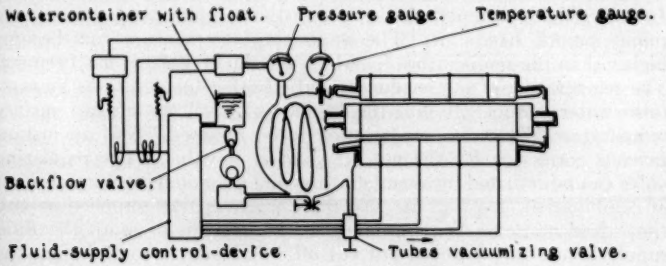

FIG. 6. Control equipment for machine.

equalizing of the fluid supplied to each opening is desirable especially with connecting tubes of different length. A slight difference in connecting- and hair tube diameters makes individual regulating valves unnecessary and the nozzle bodies simple.

High fluid pressures (small tube volume) will make for high exit velocities and a fine spray on the rotor surface. Moreover, the large tube surface in relation to the volume in the core, kept at elevated temperature, will superheat it relatively to the vacuum. This causes a finely divided mist to be spread evenly over the air-gap surfaces.

All water will be rapidly sucked back out of the tubing when connected to vacuum at the supply end. Vapor or air will fill the tubes in the core, and so leakage of the tubing not in use becomes impossible. The water flows in the condenser and is pumped through a filter in the container. A backflow valve can be used. In or out of service there cannot be any leakage in the machine (see Fig. 6).

A Regulating Device Controlled by the Temperature

With superheated vapor flowing in the condenser one can be fairly sure that all the fluid supplied to the air gap is used up. As the specific heat is small the heat quantity used is negligible compared to the heat of vaporization. Also the vapor temperature allows an accurate fluid regulation. The difference between air-gap temperature, surface temperature, and vaporizing temperature is only of academic interest.

A fluid is heavier than its vapor. With poor distribution the air gap at the bottom will be richer than at the top. This affects the stator cooling only. Instead of using one control thermometer, two or more at one or both air-gaps sides can be used. The regulating valve can be actuated by them in any combination. Special protection actuated by temperature differences and so on can be used.

Control by Temperature and Vacuum-Pressure in Combination

The vacuum pressure determines the temperature of vaporization. In emergencies so much air can get in the machine that the vacuum pump cannot handle it. The vaporizing temperature can become higher than the temperature for which the fluid regulator has been set. The temperature of the conductor and all other temperatures increase (also water cannot get into the insulation) until the air-gap surface temperature allows the vaporization to be resumed. Still an instantaneous correction for the new vacuum is of value. The regulating valve can be actuated by a temperature- and a vacuum pressure-element in combination (see Fig. 6). No more water is then supplied at any time than needed. With an increase in vacuum pressure the fluid supply is not only reduced but cut off. It is not restored before the vapor flowing in the condenser at the now desired temperature assure one of the proper air-gap surface temperatures.

With condensing turbo-generators the maximum load decreases. Thus the maximum temperature will hardly change. Obviously the higher vacuum pressure slows down the vapor flow for an instant so turbo-steam cannot get into the electrical machines. The guide rings for the wet steam supplemented by a fine gauze partition stop even the finest water droplets and allow a rapid pressure interchange.

6. CORROSION IN VAPORIZATION-COOLED MACHINES

Introduction

The oxygen, dissolved in the water, which comes in contact with metal surfaces can cause undesirable corrosion and under unfavorable circumstances erosion. The pertaining chemical formulas are $\text{Metal} + \text{HOH} = \text{MOH} + \text{H}$ and $2\text{H} + \text{O} = \text{H}_2\text{O}$. The water molecules in a fluid or surface below condensation temperature are much closer together then in a vapor, especially in a vacuum. The formation

of metal-hydroxide and hydrogen will be reduced in the last and the basic protective hydrogen layer on the metal surfaces better kept. Corrosion products and atmospheric impurities can absorb moisture at humidities down to 65 per cent and form an invisible water layer. They must be prevented from forming.

In vaporization-cooled machines the temperature can be kept at any level desired independent of the load. The vaporization temperature is between 20–40° C. instead of 100° C.; moreover, the machine is fully independent of varying and often unfavorable atmospheric conditions. Vaporization cooling and the admittance of dry air in the machine when not in service do not only keep the insulation in top condition, but the metal interior corrosion-free.

The formation of a thin protective coating on the rotor can be tolerated. The individual droplets of the water sprays will hit different surface spots all the time. Oxidation, if it occurs, will be in an even layer. The oxides will be dry most of the time. We have also the same favorable conditions as in dry hot air. Furthermore, when superheated water comes under vacuum pressure it explodes and liberates about 95 per cent of the air it contains. The oxygen will hardly come in contact with the rotor surface, therefore, and need not come in contact with the stator surface as the vaporizing water will act as a shield. The small quantity of cooling fluid needed to remove the heat losses, the high maximum closed cycle speed possible, the continuous removal of air by the air pump and impurities by the filter, they all all assist in keeping the water at a high purity and the desired slight alkalinity to inhibit corrosion. The treated boiler feedwater used for high-pressure steam installations can be used so no additional equipment is needed.

Basic Data

What are the water and air quantities involved for a 50,000 Kva machine with 2 per cent losses, to be removed by vaporization cooling only? Assume a rotor diameter of 2½ ft. and a rotor length of 10 ft. This gives a surface of 70 sq. ft. Take the average heat losses reduced to full-load losses equal to one third of the number of hours in a year and the rotor losses to one half of that. Then the rotor surface has to evaporate 20,000 gallons per sq. ft. a year. With 1 cu. cm. of air with 35 per cent O_2 per liter, 0.0245 lb. of O_2 are liberated each year per sq. ft.

For an evaluation, compare these figures with those pertaining to boilers. With a full-load cooling-cycle speed of 6 min., only 40 gal. of water are needed for the machine. These values (the vaporization cooling will not have to remove the bearing- and stator-core losses and the oxygen content will usually be smaller in practice) show better than words how little corrosion and erosion have to be feared. Machines

with a shaft seal are usually smaller in size and the cooling surfaces larger in proportion to the fluid need.

The rapid change from vapor pressure at the pertaining water temperature (vacuum) to a high pressure (water column) causes the destructiveness of cavitation. There is also no danger in vaporization-cooled machines; moreover, the water is supplied in microscopic droplets. The surrounding rotor material will, therefore, help in making any blows harmless. This is not possible with solid water jets as in turbines. As to erosion, the rotor-surface speed is about half the turbine-blade speed. The water-droplet size is controlled (not in steam turbines where sudden water cataracts are known). The metal surfaces are always at higher temperature than the fluid or vapor.

Since the induced rotor and stator currents vary continuously in intensity and direction, electrolytic corrosion is unlikely.

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NOTES FROM THE NATIONAL BUREAU OF STANDARDS*

THE FALLACY OF THE BEST TWO OUT OF THREE

In scientific and engineering investigations a single measurement of an unknown quantity is seldom considered sufficient. Two or more measurements are usually made in order to establish a check on instrumental errors, operator's errors in making readings, and the reliability of the sample. These multiple measurements have two principal advantages: They reveal by their concordance the precision of the measuring process, and they make possible the use of an average of several measurements which will, in general, have a higher precision than one measurement alone. If three measurements are made, it is fairly common practice for students to take the "best two out of three" —averaging the two values closest together and discarding the other. Recently, however, Dr. W. J. Youden of the Statistical Engineering Laboratory at the National Bureau of Standards has shown that this procedure very often leads to less precise results than the averaging of all three measurements together.

Experimental work frequently creates new situations in which the precision of the observations is not known in advance and must be determined from the same data that establish the estimated or average value assigned to the quantity being measured. While a single measurement cannot yield any estimate of the reproducibility of the value, two measurements do give a primitive indication of their precision. But in an entirely new experimental situation, two measurements may not give a reliable estimate of the precision, since any marked disagreement between the two readings may be due either to the inherent crudeness and inaccuracy of the measurement process or to some accident, such as the gross misreading of an instrument scale, which makes at least one of the measurements greatly in error. With two discordant observations and no other information, it is impossible to decide between these alternative interpretations.

Three measurements is the minimum number that can conceivably reveal one of the measurements to be unreliable in a new experimental situation. Intuition suggests that if two of the three measurements are in close agreement while the third stands apart considerably removed from either of the others, then there may be grounds for suspecting and perhaps rejecting the third value. In terms of the difference between the two in good agreement, how different may the third measurement be before it should be suspected? Since this problem is important to all

* Communicated by the Director.

who make and interpret measurements, it is a little surprising that an answer has only recently been found.

An approximate solution has been obtained in the Bureau's statistical Engineering Laboratory through an empirical study of triads drawn at random from a large group of measurements constructed to conform to the characteristics of a normally distributed set entirely free from any gross errors. In this way, it is possible to examine a great many sets of three measurements and to determine, for example, how often the two differences between adjacent values in a set of three measurements will bear a ratio of 5 to 1, 10 to 1, 20 to 1, or any other ratio that might be considered unlikely in the normal course of events. If only 1 out of 100 sets of three measurements contained a measurement differing from the others by as much as five times the difference between the two closest, then such an observation might reasonably be discarded in actual experimental data. But the empirical study actually showed that a rather unbalanced spacing between three measurements occurs quite frequently. In fact, the ratio of the two differences was as much as 16 to 1 in 10 per cent of the sets of three measurements. In this connection, it is important to note that high ratios can result when two of the readings are very close or coincident while the third is not far removed.

The mathematical solution of this problem has been obtained and the frequency of occurrence for various ratios of the two differences has been calculated. The following table shows for certain ratios the results of an empirical sampling study of 400 sets of three measuresments compared with those predicted by the exact mathematical solution of the problem.

Ratio of Large to Small Difference	Frequency in 400 Sets	Theoretical Frequency
4.0 or more	149	145.2
9.0 or more	76	69.4
19.0 or more	38	33.9

These results reveal that in an average of one out of every twelve sets, one of the measurements will be at least 19 times farther away from its neighbor than the difference separating the two closest. Since in every 12 sets 1 shows such a spacing for measurements with no gross observational errors, it appears that measurements which should be retained are often dropped from the record. The problem of deciding on standards for the rejection of observations is one of long standing. Statisticians are again attacking this problem and, in the light of recent advances in the theory of small samples, considerable progress can be expected.

THE FRANKLIN INSTITUTE

ANNUAL REPORT OF THE BOARD OF MANAGERS FOR THE YEAR 1948

Again this year it was found impracticable to ready the Annual Report of the Board of Managers for presentation at the Annual Meeting in January. That report is now presented by the President in behalf of that Board.

Membership

The total membership at the end of 1948 was 5448. During the year 763 persons were elected to membership, for a net gain of 23 in total membership during 1948 as compared to a net loss of 137 in 1947.

Our members have cooperated with the Membership Department's efforts to counterbalance the effect of the many abandonments of membership by proposing a substantial number of their friends for membership. The popular talks, under the heading of "Science is Fun" have continued to attract more and more of our members and their friends to these informal gatherings.

During the year of celebration of our 125th Anniversary continued effort will be made to increase the interest and participation of our members in the many Institute activities and to increase the membership of the Institute.

Friends of Franklin

The group of 212 individuals and companies comprising the Friends of Franklin has continued its generous support. The amount contributed by them in 1948 was $22,150.00.

Meetings

During the year seventeen stated and joint meetings with technical societies were held at which the average attendance was 232. The dinners preceding these meetings were well attended and were enjoyed by our members and their guests. Dr. Hubert N. Alyea of Princeton University gave a most interesting and popular ralk on the Chemistry of the Atom Bomb; and the film entitled "Atomic Physics" was shown here (for the first time in the Philadelphia area) and drew two large audiences.

The eleventh series of piano lecture-recitals by Mr. Guy Marriner, Director of Music, continued into the spring of 1948, with an extra recital in February, in addition to the usual request recital given in April. The twelfth series opened in October 1948, and an extra recital was given in that month. There was an increase in attendance at these lecture-recitals during 1948 over 1947, indicating continued appreciation by the public.

Scientific organizations and technical societies continued to make use of our lecture hall and other meeting rooms for their regular and special meetings. It is our policy to encourage organizations whose aims and purposes parallel our own to use our facilities for such meetings, for which only a nominal charge is made. During 1948 thirty-six such organizations used our meeting rooms for a total of 157 meetings, which, in addition to the 101 meetings held with relation to Institute activities, shows a total of 258 meetings for the year 1948.

Committee on Science and the Arts

The entire Science and Arts Committee met nine times, while thirty-six Sub-Committee meetings were held. Fourteen Medals were awarded at the annual Medal Day Excercises, two of which were Franklin Medals, one being awarded to Dr. Wendell Meredith Stanley, and one to Dr. Theodore von Karman. Four George A. Hoadley Certificates were presented to

Committee members during the year as follows:

Dr. James Barnes
Mr. Charles E. Bonine } For thirty-five years of service.
Mr. Benjamin Franklin
Dr. Frederic Palmer —For twenty-five years of service.

Journal of the Franklin Institute

Our Journal, one of the oldest continuously published technical journals in the country, maintained its high standards of technical excellence in the 41 papers which appeared in the twelve issues for 1948. During the year, 62 manuscripts were submitted for consideration, of which 10 were published and 20 were added to the lengthy list awaiting publication. Each month approximately 4658 copies were distributed—3177 to members, 617 to domestic subscribers, 380 to foreign subscribers, 112 to "Friends of Franklin," and 372 in exchange for other publications.

During 1948 the following changes in Journal policy were effected: (1) the incorporation into each issue of one "general interest" paper, intelligible to the lay reader and yet of interest to technical men and scientists; (2) the expansion of the Book Reviews section, with all reviews by technically qualified contributors; and (3) the addition of a section of "Museum Notes" designed to place on permanent record the outstanding activities of that department of the Institute.

As evidence of the esteem in which our Journal is held, several hundred dollars worth of back files have been sold to libraries, industrial plants and government agencies during the past year.

Library

The additions to the Library during 1948 were as follows:

	Bound Volumes	*Unbound Volumes*	*Pamphlets*	*Maps*
By gift	328	324	876	224
Binding	816			
Purchase	626	46		
	1770	370	876	224

Total additions of all kinds: 3240.

Gifts were received from members and friends of the Institute, and through exchange from many scientific societies and institutions.

Complete specifications of patents from United States, Great Britain and Switzerland were received throughout the year. 800 periodical publications were received regularly through exchange and subscriptions, and 672 books were purchased. 13,184 photostat prints were furnished from material on file in the Library. 11,278 persons consulted the Library collection. Of this number 8033 were members and 1580 were members of the staff of The Institute Laboratories. There were 5458 telephone calls for technical information.

The total contents of the Library as of January 1, 1949 were:

131,101 Volumes
47,593 Pamphlets
4,667 Maps

Museum

Attendance:

The following tabulation shows the attendance at the Museum and Planetarium:

	Paid	*Free*	*Total*
1947	178,724	72,247	250,971
1948	160,428	71,559	231,987

As in prior years all public and parochial school children from Philadelphia continued to be admitted to the Museum and Planetarium without charge when attending in groups accom-

panied by a teacher. When attending individually, the children paid only the Federal admission tax.

Exhibits:

This year has been marked by unusual activity in major changes of exhibition space. Owing to changes in the location of some research laboratories, an area in the Electrical Communications Section was restored for exhibit purposes and a portion of the Physics Section had to be sacrificed. Advantage was taken of the former change to clear the entire room in order to provide space for the Atomic Energy Exhibition furnished by the Brookhaven National Laboratory. The original exhibits displayed in the room were distributed throughout other sections of the Museum.

As was anticipated, the Atomic Energy Exhibition proved to be very popular. As indicative of the appeal which the subject makes to young people, nearly 400 high school students accepted the invitation to attend a lecture in which an appeal was made for volunteers to serve as demonstrators of the individual exhibits. Some 175 volunteered, and from these a selection was made. The enthusiasm of these young people is deserving of the highest praise.

The Physics Section has been re-organized to accomodate its exhibits within a smaller space.

Toward the end of the year a very attractive exhibit room provided by the Lee Rubber and Tire Corporation was opened to the public, in which the story of rubber is told. The sources, distribution, and application of natural and synthetic rubber are graphically shown, while well designed exhibits of the push-button type demonstrate the properties of rubber, and explain its use in the manufacture of an automobile tire.

The issue of the Franklin half-dollar was marked by the arrangement of an exhibit illustrating how coins are made from the original designs. In the preparation of this exhibit we had the cooperation of the U. S. Mint.

Additions:

The policy of carefully screening gifts and loans offered to the Museum, enforced upon us through restrictions upon the exhibit space, has been rigidly followed, but 57 new exhibits were accepted. Among the gifts were: a model of a television studio from the Philco Corporation; an Adams reflex camera from Mr. M. G. Curtis, Bala; a five-stringed violincello from Mrs. Karapetoff, New York; original wind tunnel devices bequeathed by Orville Wright; and a fluorescent lighting exhibit from the General Electric Company. Noteworthy among the loans were: a display of Fiberglas from the Owens-Corning Fiberglas Corporation; a squeeze press from the Tabor Manufacturing Company for the Steel Castings exhibit; an operating television set from the Radio Corporation of America; a Ramage Press from the John Wanamaker Company; an automatic film projector, a primary flight trainer, and other material from the United States Navy, Special Devices Division; a dump truck model from Mr. W. L. Aiken, Ardmore; an iron chest with Franklin associations from Mr. R. Riling; a recognition-type electronic reading machine for the use of the blind from the Veterans Administration; and a signed plaster cast of the Houdon bust of Benjamin Franklin from Mr. A. L. Wolfe, New York.

Special Activities:

The monthly exhibitions of industrial photographs in the Photographic Salon and the showing of industrial films in the Little Theatre was continued with satisfactory results.

A monthly television program over station WPTZ has been conducted by Mr. A. D. Hollingsworth in which museum exhibits have been freely introduced. The fifth series of radio programs prepared with the cooperation of station WFIL and the public, parochial, and private schools of the area opened in October. Mr. Armand Spitz again planned the programs and supervised the script writing. This series of broadcasts, called "Science is Fun," has been selected by the Education Section of the Supreme Headquarters Staff for the Allied Powers for translation into Japanese and broadcast in Japan.

The figures covering the Museum attendance of groups and individual students (included in the totals given above) are as follows:

	1944	1945	1946	1947	1948
Paid	27,225	38,368	64,396	65,527	73,500
Free	33,633	42,675	52,140	57,207	48,816
Total	60,858	81,043	116,536	122,734	122,316

Work has continued with the Schools of Education of the Universtiy of Pennsylvania and of Temple University and with the State Teachers' Colleges. This cooperation has taken the form of lectures and conferences in the colleges and also of informal vistis to the Museum by groups of student teachers. In-service classes, affiliated with the Museum's activities, have been held and the Department of Museum Education has been consulted in connection with curriculum planning.

There has also been continued cooperation with the Philadelphia Board of Education through its Curriculum Office, Visual Aids Department, Adult Education, and other functions. The well established association with the parochial and private schools in the area, as well as with the Boy Scouts, Girl Scouts, and similar organizations has been maintained.

The number of special planetarium demonstrations designed for school pupils has greatly increased. In connection with the work of the Science Council, tests and interviews to recognize young people of outstanding scientific ability have been held, with a view to assisting them in securing employment, admission to college, or attempts to obtain scholarship aids. Preliminary work of the Science Fair has been undertaken and co-sponsors found in the proprietors of the Philadelphia Inquirer.

The normal program of the Fels Planetarium had to be curtailed because of a major repair job undertaken on October 26th to replace the main bearing of the instrument. This repair, together with the re-painting of the dome, and the refinishing of the floor was completed on November 25th. This is the first time to our knowledge that any major repair work to an instrument has been undertaken outside the Zeiss plant. It may be noted that on completion of the work the operation of the instrument was noticeably quieter and more satisfactory. We were fortunate in having the cooperation of SKF's expert engineers in replacing the bearing and in having it presented to us as a gift by the SKF Industries.

In spite of this handicap, 901 planetarium [demonstrations] were given during the course of the year, attended by 159,401 visitors. As in the past the planetarium demonstrations were of two categories—the conventional demonstration in which fundamental astronomical information is conveyed in non-technical language, and the more spectacular type of demonstration which is intended to arouse unusual attendance and promote interest through the use of special effects and devices.

As in former years extensive extra-mural lecture engagements were filled by members of the Planetarium staff.

Staff:

At the end of the year Dr. Roy K. Marshall resigned from the staff in order to accept a post with the University of North Carolina. Dr. I. M. Levitt, who has been associated with the Fels Planetarium since its inception, was appointed to succeed him as Director of the Fels Planetarium and Associate Director of Astronomy, Seismology, and Electrical Communications in the Museum.

Personnel

On January 1, 1948 there were 469 on our payroll. During the year 168 new employees were taken on our staff and 164 were separated, leaving 473 as of January 1, 1949. There were five deaths in the course of the year: James Brett and Clarence Taylor (both of whom joined the Institute in 1933 before the opening of the Museum), William Brauner (who was killed in an airplane accident while engaged in research work for the U. S. Air Forces), Joseph Berry and Joseph Sepsey.

During the year a study was made of ways and means of giving greater economic security to our employees, particularly as a substitute for our not being subject to the Federal Social Security Act. In line with this, a contributory group insurance plan was authorized by the

Board of Managers and became effective January 1st (on January 31st, at the end of the eligibility period, 88 per cent of those eligible had joined). This insurance plan provided $1000 life insurance for each employee and sickness and accident benefits depending upon the salary classification of the employee.

Hostess Committee

The bi-monthly luncheon meetings of the Hostess Committee have featured this season visits to various sections of the Museum and Laboratories.

In December when Beatrice Fox Griffith's new book *Historic Stars and Comets* was released a special luncheon was tendered Mrs. Griffith. Mrs. Griffith's interest in the Institute was indicated by her desire that all profits from sales of her book at the Institute be turned over to the Hostess Committee for use in connection with Institute activities.

The committee also continued its work on projects begun in the preceding season. In December the newly decorated Girls Recreation Room was made available to the women employees of the Institute. The expressions of appreciation received from the girls and their daily use of this very attractive room indicate how worthwhile this project was. The results of the efforts of the Garden Committee are beginning to show and by summer it is hoped that the appearance of the lot beside the Laboratory Building will be greatly improved.

Research Laboratories

Franklin Institute Laboratories for Research and Development:

Perhaps the most interesting feature of the steady progress made by these Laboratories during 1948 was the increase in industrial work, while the Government work continued at a level only slightly higher than in 1947. The staff, exclusive of shop personnel, part-time employees, and consultants, was composed of 246 members as of December 31, 1948 compared with 260 on December 31, 1947. The three operating Divisions continued to function in their respective specialized fields.

The entire Laboratory Annex, formerly known as the Court Building, was occupied in March, 1948. The additional space thus acquired, together with the installation of a well equipped Electronics Laboratory on the second floor of the Museum Building, brought the total space occupied by the Laboratories to 55,994 sq. ft. The former Electronics Laboratory on the second mezzanine was retained as a stock room and engineers' laboratory, while the space on the third floor previously used for research work was released for a Girls' Recreation Room, referred to more fully in the report of the Hostess Committee. Since the total space occupied as of January 1, 1948 was 49,107 sq. ft., there was an expansion of 6,887 sq. ft. during the year.

New Equipment.—The principal items of new equipment acquired during the year include altitude and cold test chambers; testing ovens with very accurate control; the addition to the former photoelastic equipment in the Halstead Laboratory of a strain indicator and strain recorder for use with electric strain gages and a set of equipment for determining stresses by using brittle lacquers; a complete unit for preparing high polymers, especially GR-S synthetic rubber; a spectrograph of high light sensitivity, using the Image Orthicon to obtain rapid time-resolution in combustion studies; an efficient rubber mill; and a ten-channel infrared spectrograph designed for extremely rapid coverage of the infrared region. The last two items were designed and developed in the course of project work. In addition to these major items, the supply of equipment and test facilities has been enlarged so that a variety of problems in the various fields can be attacked successfully.

Work Performed in 1948.—There has been a gradual inclination toward specialization in certain categories, rather than a tendency to attempt each kind of scientific problem that may be offered for consideration. Some of the specific kinds of work performed during 1948, which are particularly adaptable to meeting the needs of industry, included:

a. Physics of the Solid State: Research on thermocouples, carbon film resistors, photoconductivity, friction and wear, and stress corrosion and fatigue. New techniques with the electron microscope were applied to metallographic and other problems.

b. High Polymer Physics: Properties and preparation of synthetic rubber of improved quality; development of rubbers for low temperature applications; application of ultrasonics to such problems as polishing castings; and research on asphalts, sealing compounds, and abrasives.
c. Radiation and Thermodynamics: Research on gaseous ignition and combustion; thermal properties of gases; and development of sensitive and stable infrared detectors and the application of infrared techniques.
d. Electrical Instrumentation: Basic studies on magnetic recording, techniques, and equipment; the development of an automatic recorder of voltage and current levels for use in electrolytic research; and the construction of a machine for determining the magnetic characteristics of samples.
e. Instrumentation other than Electrical: Development of a resonance method for testing the quality of abrasive wheels; and the study of the physical action of nebulizers used in treating respiratory conditions.
f. Aeronautics: The design of an interlocked air traffic control system.
g. Stress Analysis: By use of electrical strain gages and brittle lacquer, determinations were made of stress in plates of spotwelded joints.
h. Photoelasticity: Studies of stress trajectories and isoclinics in models of spot-welded joints; applications to gear teeth and other mechanical items; and determinations in double glazing units.
i. Sensory Devices: Continued development of sensory devices for the physically handicapped, including a projection magnifier for the semi-blind. A major requirement of this program is for a design which can be produced at a price within the reach of the majority of those afflicted.

It is difficult to convey even the semblance of a picture of the work performed for the Government during 1948 because of its confidential classification. However, some of the accomplishments were:

a. Aeronautics: The development of pressure and speed recorders, special guidance and control systems, and airborne fire control equipment; research in instrumentation for supersonic aircraft; and the establishment of design criteria for aeronautical use. Improved recording accelerometers also were developed. Moreover, the Air Technical Index was established in the large file of aeronautical publications.
b. Electrical Instrumentation: The analysis of control stability requirements, and the design of a controller for a marine turbine installation.
c. Mechanical Designing: Mechanical designers and draftsmen were engaged in designing and developing intricate ordnance mechanisms, and in assisting in the upper air research program.

New Features.—There has been a noted increase in the number of technical papers prepared by members of the staff and published in scientific magazines, many of which were presented in person before regional or national meetings of such organizations as ASME, AIEE, Textile Research Institute, and others. This increase of technical publications is due in part to the new policy of The Franklin Institute to encourage their preparation and to procure reprints of the papers published for distribution to a selected group of approximately five hundred commercial firms, research laboratories, and scientific individuals, crediting the author, the medium of publication, and the Institute. Plans were made, for 1949, to have abstracts of the papers published as a regular monthly feature in the JOURNAL OF THE FRANKLIN INSTITUTE.

Other new features introduced during the year which contribute toward better public relations and/or employee relations include:

a. Members of the technical staff continued to take active part in various technical and scientific organizations by serving as committee members or officers.
b. The Franklin Institute, during the past eight months, has been the headquarters for the Aviation Writers Association.
c. Invitations have been extended to the Army, Navy and Air Forces for the establishment

of research and development groups of reserve officers under the auspices of The Franklin Institute.

d. Establishment of conducted tours of special groups through the Laboratories, including scientific men and women who may be attending special seminars or meetings at The Franklin Institute, such as were arranged for the members of the Economic Mobilization Course in November 1948. Enlargement of this policy was adopted to include the staff and members of special committees of the Institute; a selected group of heads of industrial organizations by invitation; and an "Open House" to be held in the Spring, which may be attended by anyone interested and which should be a means of acquainting the people of Philadelphia with the types of service available.
e. Sponsorship of "The Filter." This paper, published semi-monthly, has proven an effective agent for disseminating information of interest to all Institute personnel.
f. Considerable work was devoted to publishing a new brochure which was ready for distribution in the spring of 1949 and which is expected to serve the purpose of familiarizing industry with the facilities of the Laboratories.

From the above composite report of the Laboratories for the year 1948, it is evident emphasis has been placed on basic research for industrial organizations. In some cases, the Laboratories are actually operating as the research laboratories for small concerns, in addition to performing specialized services for large companies who maintain their own laboratories. Continued opportunity to serve industry at a constantly increasing rate seems assured.

The Bartol Research Foundation:

The Bartol Foundation is engaged in work under the following heads:

1. Researches in nuclear physics and cosmic rays.
2. Researches in matters pertaining to thermionic work.
3. Work having to do with the development and construction of a new Van de Graaff generator for positive ions and for a voltage range between 5 and 10 million volts.
4. Miscellaneous researches sponsored by the Bartol Foundation itself, including the development of a small linear accelerator.

Cosmic ray work has involved researches using a B-29 bomber; researches up to very high altitudes employing radiosonde balloons; and investigations up to 15,000 ft. on Mount Evans.

The present Van de Graaff generator (a two million volt machine) has been functioning admirably during the year and has been used in many researches.

Work on the new Van de Graaff generator has progressed very satisfactorily. A great many of the parts have been completed and are awaiting installation. Also much research concerned with the development of the machine has been carried out. Preliminary plans for the building have been drawn and we are awaiting final decision as to the site. When this is made, plans for mounting the large tank, which is already completed and tested, will immediately be put in operation.

The Biochemical Research Foundation:

The year 1948 was a good year for The Biochemical Research Foundation, one marked by the finding of some new and very interesting leads in the study of cancer and by a closer application of chemical knowledge to the biological problems in hand, with considerable success.

Great value was derived from the closeness of association of the Foundation with the University of Delaware, seven Ph.D. students of which have been working on projects pertinent to the Foundation's research under the direction of Professor W. A. Mosher of the University, the chemical consultant of the Foundation. New assignments are expected to replace the students who graduate, with continuance of the benefit to the Foundation.

The Foundation has found its personnel to be in great demand by other institutions, and has a substantial replacement problem to solve in consequence. Satisfactory replacements have been found, however, and absorbed into an integrated and correlated force now numbering forty-seven persons.

The only major replenishment of equipment has been the replacement of a 19-year old X-ray apparatus, now becoming obsolete, by newly-purchased equipment.

A number of the Foundation's publications have attracted considerable attention, notable among them being the book "Neutron Effects on Animals" which gives promise of selling out its first edition this year. The requests for reprints of some items have been so numerous as to constitute a minor embarrassment from the financial standpoint, and a substantial stock of those most in demand has been assembled to meet this situation.

Public Relations

During 1948 there continued, with some intensification, sustained effort towards promotion of knowledge of the Institute's activities and general functioning among the several publics to whom its varied potentialities might appeal. This was done through the usual publicity channels under the auspices of the Public Relations consultants who have been retained to guide the Institute's program in this field since 1943, with two members of the Institute staff assigned to assist them.

Public Relations counsel was readily available to, and was increasingly sought and used by, the Institute's other agencies in basic planning, in promotion, and in special problems of all kinds.

In addition to the normal meetings and the usual annual events, special promotions of one kind or another were launched as occasion offered, among them being the ceremonies held at the Institute, with the Director of the Mints as guest, to launch the new Benjamin Franklin half-dollar.

Finances

The financial position of The Franklin Institute at December 31, 1948, as compared with December 31, 1947, is indicated in the following comparative summarized statements of assets and liabilities:

Assets	*December 31, 1948*	*December 31, 1947*
Current assets	$ 692,054	$ 662,753
Fixed assets	4,466,598	4,366,250
Less: Reserve for depreciation	(313,943)	(139,137)
Endowment fund investments (including Notes Payable contra)	1,711,285	1,681,215
	$6,555,994	$6,571,081
Liabilities		
Notes payable (included in Endowment funds contra)	$ 470,000	$ 319,000
Liabilities, deferred income, and reserves	219,785	249,195
Endowment funds	1,711,285	1,681,215
Capital stock and contributed funds	3,962,514	3,965,494
General appropriation fund (surplus)	192,410	356,177
	$6,555,994	$6,571,081

The results of operations for the year 1948 as compared with 1947 are shown in the following comparative statements of income and expenses:

	1948	*1947*
Operating Revenue:		
Members dues	$ 66,035	$ 59,092
Museum admissions and other income	93,590	101,410
Other Institute activities	34,616	30,527
Laboratory research projects	1,747,302	1,436,903
Total operating revenue	1,941,543	1,627,932

	1948	1947
Operating Costs and Expenses:		
Museum	$277,815	$279,302
Library, less amounts transferred	51,247	46,749
Other Institute activities	66,992	46,998
Laboratory research projects	1,726,694	1,426,864
Administrative and general expense, less amounts transferred	105,067	115,586
Total operating costs and expenses	2,227,815	1,915,499
Operating Loss	286,272	287,567
Other Income:		
Income from endownment funds	70,314	68,956
Donations from Friends of Franklin	22,150	24,071
Appropriation, Commonwealth of Pennsylvania	34,500	31,583
Service fees from Bartol and Biochemical Foundations	13,453	14,869
Miscellaneous	1,310	1,354
	141,727	140,833
Deficit before other expenses	$ 144,545	$ 146,734
Other Expenses:		
Interest (included in endowment income above)	12,665	4,132
Miscellaneous	8,577	11,386
	21,242	15,518
Net deficit for the period	$ 165,787	$ 162,252

As will be seen from the foregoing statement, the operations for the year 1948, after including in costs a charge for depreciation of buildings and equipment amounting to $174,843, resulted in a deficit of $165,787. The deficit for the preceding year of 1947 was $162,252 after a charge for depreciation of $139,137. The present budget for 1949 indicates a deficit of $80,000 after depreciation of $174,000.

In our report for last year the need of the Institute for unrestricted endowment and gifts was pointed out. It is with gratitude that we acknowledge the gift of $2,000 from Dr. George W. Outerbridge in memory of his father, the late Alexander E. Outerbridge, and the gift from Mrs. Edward G. Budd and Mr. Edward G. Budd, Jr., for the establishment of the annual Edward G. Budd Lecture.

Our financial needs continue. It is hoped that there are those who have faith in the educational and scientific work in which we are engaged who will help us to meet those needs more adequately.

JOURNAL OF THE FRANKLIN INSTITUTE

The following papers will appear in the Journal within the next few months:

MINORSKY, N.: Energy Fluctuations in a van der Pol Oscillator.

MARIN, JOSEPH: Stress-Strain Relations in the Plastic Range for Biaxial Stresses.

DEVLIN, JAMES A., WALLACE M. MCNABB AND FRED HAZEL: Preparation of Vanadium Pentoxide Sols by Ion Exchange.

COULSON, THOMAS: The Story of Aids to Navigation.

DUBILIER, WILLIAM: Development, Design and Construction of Electrical Condensers.

FANO, ROBERT M.: Theoretical Limitations on the Broadband Matching of Arbitrary Impedances.

FANO, ROBERT M.: A Note on the Solution of Certain Approximation Problems in Network Synthesis.

JACOBSEN, LYDIK, R. L. EVALDSON AND R. S. AYRE: Response of an Elastically Non-Linear System to Transient Disturbances.

LIBRARY

The Committee on Library desires to add to the collections any technical works that members would wish to contribute. Contributions will be gratefully acknowledged and placed in the library. Duplicates received will be transferred to other libraries as gifts of the donor.

Photostat Service. Photostat prints of any material in the collections can be supplied on request. The average cost for a print 9 × 14 inches is thirty-five cents.

The Library and reading room are open on Mondays, Tuesdays, Wednesdays and Fridays from 9 A.M. until 5 P.M.; Thursdays from 2 P.M. until 10 P.M.; and Saturdays from 9 A.M until noon.

RECENT ADDITIONS

ARCHITECTURE AND BUILDING

MAGNEL, GUSTAVE. Prestressed Concrete. 1948.

ASTRONOMY

ROSSELAND, SVEIN. The Pulsation Theory of Variable Stars. 1949.

CHEMISTRY AND CHEMICAL TECHNOLOGY

Advances in Catalysis and Related Subjects. Volume 1. 1948.

BURK, ROBERT EMMETT AND GRUMMITT, OLIVER. High Molecular Weight Organic Compounds. 1949.

BURK, ROBERT EMMETT AND GRUMMITT, OLIVER. Recent Advances in Analytical Chemistry. 1949.

THE CHEMICAL CORPS ASSOCIATION. The Chemical Warfare Service in World War II. 1948.

DEWAR, M. J. S. The Electronic Theory of Organic Chemistry. 1949.

GROSS, MARTIN AND GREENBERG, LEON A. The Salicylates; a Critical Bibliographic Review. 1948.

PANNELL, ERNST V. Magnesium. 1948.

SMITH, HENRY MONMOUTH. Torchbearers of Chemistry. 1949.

WEISER, HARRY BOYER. A Textbook of Colloid Chemistry. Ed. 2. 1949.

CIVIL ENGINEERING

KNIGHT, BERNARD H. Soil Mechanics for Civil Engineers. 1948.

ELECTRICITY AND ELECTRICAL ENGINEERING

BRIGHT, ARTHUR A. The Electric Lamp Industry. 1949.

HARNWELL, GAYLORD P. Principles of Electricity and Electromagnetism. Ed. 2. 1949.

MORROW, L. W. W. Electric Power Stations. 1927.

ELECTRONICS

ZWORYKIN, VLADIMIR KOSMA AND RAMBERG, EDWARD G. Photoelectricity and its Applications. 1949.

ENGINEERING

ALDEN, JOHN L. Design of Industrial Exhaust Systems. 1948.

DIETZ, ALBERT GEORGE HENRY. Engineering Laminates. 1949.

GODDARD, ROBERT H. Rocket Development; Liquid Fuel Rocket Research. 1948.

MORLEY, ARTHUR. Theory of Structures. Ed. 5. 1948.

O'NEILL, JOHN JOSEPH. Engineering the New Age. 1949.

FOOD

SHERMAN, HENRY CLAPP. Food Products. Ed. 4. 1948.

MANUFACTURE

GUYÉ, RENE P. AND BOSSART, MAX. Horologerie Électrique. 1948.
International Industry Yearbook. 1948.

MATHEMATICS

COLLATZ, LOTHAR. Eigenwertprobleme und ihre Numerische Behandlung. 1948.
FISHER, RONALD AYLMER. The Design of Experiments. 1949.
TARSKI, ALFRED. Cardinal Algebras. 1949.

MECHANICAL ENGINEERING

ANDERSON, J. W. Diesel Engines. Ed. 2. 1949.
HØEGH, CARL. The Cylinder Wear in Diesel Engines. 1949.

METALLURGY

BURKE, J. E. ET AL. Grain Control in Industrial Metallurgy. 1949.
STANLEY, JAMES K. Metallurgy and Magnetism. 1949.

PHARMACY AND PUBLIC HEALTH

Modern Drug Encyclopedia and Therapeutic Index. Ed. 4. 1949.

PHYSICS

CARLIN, BENSON. Ultrasonics. 1949.
EYRING, CARL FERDINAND. Essentials of Physics. 1948.
FERRI, ANTONIO. Elements of Aerodynamics of Supersonic Flows. 1949.
MILNE, EDWARD ARTHUR. Kinematic Relativity. 1948.
YAGODA, HERMAN. Radioactive Measurements with Nuclear Emulsions. 1949.

SANITARY ENGINEERING

BABBITT, HAROLD EATON AND DOLAND, JAMES J. Water Supply Engineering. Ed. 4. 1949.
SOUTHGATE, B. A. Treatment and Disposal of Industrial Waste Waters. 1948.

SCIENCE

STIMSON, DOROTHY. Scientists and Amateurs, a History of the Royal Society. 1948.
SULLIVAN, J. W. N. The Limitations of Science. 1949.

MUSEUM

A MASTERPIECE RESTORED

When The Franklin Institute moved into the present building generous donors offered exhibits to furnish it. Among the gifts was a blackened mass of cams, gears, and levers which had obviously passed through a destructive fire. The donor could give little information concerning the fragments other than that they had formed an automaton capable of writing and drawing. Only a few incomplete pictures had survived the fire but it was clear from these that the automaton or android was of an unusual nature. One of our mechanics, the late Charles Roberts, undertook to rebuild the mechanism. After several months of patient labor he succeeded in reconstructing the mechanism, and the staff of the Museum were aware that they possessed a masterpiece of the mechanic's art. It was attributed by its donor to Robert Mältzel, inventor of the metronome.

Then one day a reader in the Library chanced upon an account in the *Edinburgh Encyclopaedia*, published in 1812, of an android made in London by Henri Maillardet, manager of the famous Jaquet-Droz firm of watchmakers. The only difference was that the early description was of a kneeling boy writing, whereas The Franklin Institute figure represented a

seated lady. However, a member of the staff submitted the writings and drawings, seven in number, to a very careful scrutiny, with the result that what had formerly been regarded as decorative detail on one drawing proved to be the statement, written in French, that the drawing was "done by Maillardet's automaton."

It was known that Maillardet's writer and draughtsman had passed through the hands of several well known showmen in the nineteenth century. It had last been reported as being in the Peiping Museum. However, further research here and in Switzerland has served to prove that The Franklin Institute automaton is Maillardet's masterpiece.

The principal part of any writing or drawing mechanism is that which initiates and controls the movements of the hand. The other bodily movements that contribute to realism can be simulated without much difficulty, for they need not be accurate. But the motions of writing or drawing must be very closely controlled if the work produced is to be readable or understandable. It is also necessary that the control be carried out in three dimensions. since the machine must make a two-dimensional drawing and also lift the pen off the paper, Thus three directional components must be provided to move the writing arm of the automaton.

By far the most convenient method of satisfying these requirements is to use a set of three metal disc cams, which Maillardet adopted. The arm joints have the same play as those of the human arm, except that the wrist does not bend. There were no electric motors available when Maillardet built his automaton 150 years ago, but he constructed spring motors to operate his mechanism smoothly. The "brain" of the automaton is three groups of cams. Two groups produce horizontal and vertical motion on the drawing, while the third group takes the pen on and off the paper. Each disc in a group has a mate in each of the other groups with which it operates simultaneously. Indexing the cams is done by a large drum fitted with a single helical rib. The drum is rotated by the spring motor, and on its end are engraved the titles of the seven drawings and verses, so that the operator can set the drum for any desired drawing. Each drawing requires several sets of cams for its execution, and at the end of each revolution the cams stop with the followers resting on transverse bars. They remain undisturbed as the indexing drum automatically slides the next set of cams into alignment, so that the work can continue. The time spent in this operation is utilized to advantage, for the doll raises her pen, straightens up, and looks critically at the paper, as if deciding what to draw or write next.

The Jaquet-Droz automata in the Neuchatel Museum in Switzerland do not possess such an extensive repertoire as does the Maillardet automaton but their work is more delicate. However, the very delicacy of the work does not permit frequency of operation. In order to witness them in operation, the visitor must time his visit to the Museum for a Sunday. The Maillardet writer and draughtsman operates cheerfully every day and produces an average of 10,000 drawings and verses during the course of the year.

V.2
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THE FRANKLIN INSTITUTE LABORATORIES FOR RESEARCH AND DEVELOPMENT

***Abstract of* Combustion Studies Using the Golay Photothermal Detector with an Infrared Monochromator.**[1]—J. T. AGNEW.[2] At the Franklin Institute Research and Development Laboratories, there is a research project in which certain techniques of infrared detection and spectroscopy have been developed.

In recent years, it has become obvious in combustion research that new methods must be developed in order to achieve an insight into the reaction kinetics of combustion processes. Two types of information needed are temperature, and composition of the reactants as a

[1] Contributed by the Heat Transfer Division and presented at the Semi-Annual Meeting, Milwaukee, Wis., May 30–June 5, 1948, of The American Society of Mechanical Engineers. Published in *Transactions of the ASME* for February, 1949.

[2] Research Engineer, The Franklin Institute Laboratories for Research and Development, Philadelphia 3. Penna.

function of time. Knowledge of these two parameters, together with pressure, would allow a more accurate determination of the actual conditions existing at a given instant in a combustion process, such as the explosion in the cylinder of an internal-combustion engine. A better and more thorough understanding of the actual conditions existing throughout the combustion process ultimately would lead to a more efficient conversion of the potential energy, stored in the fuel, to useful energy.

An experimental approach to the investigation of the parameters mentioned is the determination, as a function of time, of the spectral distribution of the radiant energy given off during the combustion. It would be desirable to determine this spectral distribution over as large a portion of the spectrum as possible, since many of the radiating components have an identifying band structure in various regions of the spectrum. A rather large region of the spectrum is covered by infrared detectors. Some of these detectors are even sensitive throughout the visible spectrum and partially into the ultraviolet region.

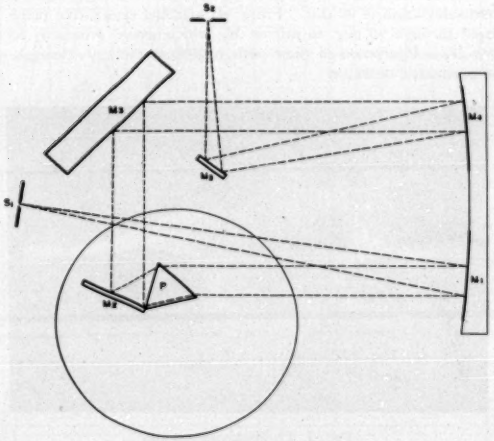

FIG. 1. Schematic diagram of monochromator.

Another factor in favor of using infrared detectors in the initial phase of radiant-energy investigations is that, in the range of temperatures expected to be encountered, perhaps 530 deg. K to 4000 deg. K, the peak radiant intensity from a black radiator, operating in this same temperature range, lies in the infrared region of the spectrum from approximately 0.72 to 5.4 microns. Finally, it is known that many polyatomic molecules have characteristic radiation bands in this same region of the spectrum, for example, the water vapor band at 2.7 microns and the carbon dioxide band at 4.4 microns.

The instrumentation for the first preliminary combustion studies consisted of: a combustion bomb equipped for spark ignition, an infrared monochromator which utilized a Golay photothermal detector as the sensitive element, an oscilloscope for presenting the information from the detector, and a 35-mm. camera for recording it.

The method used for operating the photothermal detector is as follows: A small volume of gas is contained in a chamber, either end of which is closed by a thin collodion membrane. A thin film of aluminum is evaporated on one membrane and a thin film of antimony on the other. The aluminum film acts as an absorber of radiant energy with the result that the enclosed gas is heated slightly and expands, causing a dilation of the antimony film. This film has the prop-

erties of an optical mirror and, in conjunction with a meniscus lens, causes the image of half of an illuminated lined grid to be focused in the plane of the other half, thus producing a light-modulating system. The light modulation caused by the dilating antimony mirror is detected by a light-sensitive photoconductive cell and amplified.

A detector of this type was used in conjunction with a special low-dispersion monochromator, the schematic diagram of which is shown in Fig. 1. The two small sections of the same large parabolic mirror, used, respectively, for collimating M_1, and focusing M_4, are essentially equivalent to two small off-axis parabolic mirrors. The radiation enters slit S_1 and strikes parabolic mirror M_1. From there parallel rays travel to the 60-deg. prism of sodium chloride. The prism and mirror M_2 are arranged according to the Wadsworth type of mounting, wherein the rays that pass through the prism at the angle of minimum deviation are reflected from plane mirror M_2, at an angle to the rays incident to the prism-mirror combination of twice the angle θ between the perpendicular to the prism base and a line parallel to the face of M_2.

Hence, for this monochromator, the total deviation of the rays which pass through the prism at minimum deviation is 90 deg. From M_2, parallel rays strike plane mirror M_3 and are again deviated through 90 deg. to mirror M_4, which would ordinarily focus them at S_1, but plane mirror M_5 is interposed in their path to deflect the rays through slit S_2 which is mounted on the pneumatic detector.

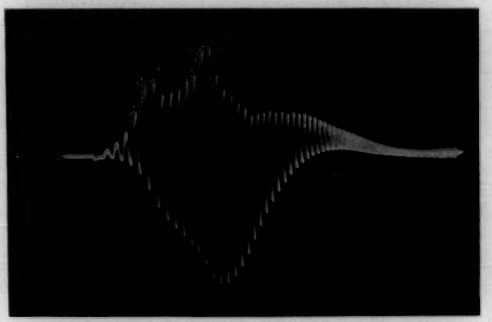

FIG. 2. Typical oscillograph.

The electronic signal obtained from the light-sensitive cell of the detector is amplified and fed to an oscilloscope and the tracing on the screen photographed.

The use of this low-dispersion monochromator with the pneumatic detector permits the determination of the spectral distribution of phenomena existing for very short intervals of time (of the order of a few milliseconds), or the determination of the spectral distribution, as a function of time, for phenomena existing for longer periods of time. A study of the latter type has been carried out and will be described.

A methane-air mixture containing approximately 8 per cent methane was ignited by means of a spark in the bomb. The combustion chamber was approximately 12 in. long and 6 in. in diameter.

After the bomb had been filled with the combustible mixture, the shutter was set in motion to intercept, at intervals, the radiation emitted from the burning gas through the sodium chloride window. The monochromator was adjusted to the desired wavelength and the spark ignited. The sweep circuit of the oscilloscope was set in motion simultaneously, and a short time-delay relay allowed the sweep to travel a short distance before the spark was ignited. With the ignition of the spark, the combustion process began, and the energy emitted from the reaction at a given wavelength, as chosen by the monochromator, was sent to the gas cell

of the pneumatic detector. The entire process was repeated for a series of wavelengths, 65 different ones being taken in the spectral region from 1 micron to 11 microns.

A typical oscilloscope trace is shown in Fig. 2. This trace was obtained by a simple time exposure during the combustion. The trace, as shown in Fig. 2, traveled from left to right, the first downward streak from the left being caused by the ignition of the spark. The maxima and minima of the trace tended to equalize around a centralized base line which itself tended to shift, depending upon the strength of the signal. The actual intensity, at a given time, was obtained by measuring the distance vertically downward from a maximum to the line joining the two minima on either side of the maximum being measured. It can readily be seen in Fig. 2 how this distance builds up and decreases with time.

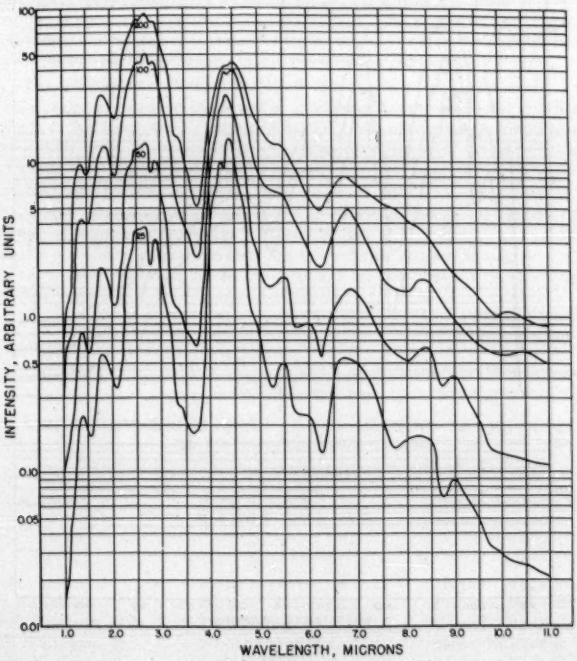

FIG. 3.

Figures 3 and 4 represent spectral intensity as a function of time for the radiation emitted during the combustion process. In Fig. 3, progressing upward, the successive curves are for times of 25, 50, 100, and 200 msec. The curves in Fig. 4 are, progressing downward, for times of 300, 400, and 500 msec. The curves are drawn with the intensity ordinate on a logarithmic scale. This was necessary because of the large range of intensities covered. The curves as presented are not corrected for the overlapping effect, due to the use of a fairly wide slit of 380 microns.

The complete analysis of the curves will be presented in a later paper. However, the

following remarks apply to the curves as presented: At 25 msec. there are well-defined emission peaks at 1.42 and 1.80 microns, two broad peaks covering the range 2.4–2.9 microns and 4.1–4.6 microns, and other peaks at 5.5, 6.0, and 6.75 microns. There are irregularities, almost completely masked, in the range 3.2–3.7 microns. Methane is known to have a band in this region so that the minimum in the vicinity of 3.3 microns in the early stages of the combustion may be absorption by unburned methane. The development of these peaks can be followed with time. The rather complicated structure of the 2.4–2.9 micron and 4.1–4.6 micron bands is probably somewhat due to self-absorption. The OH radical is known to have a fundamental frequency corresponding to a wavelength of 2.8 microns. A well-defined minimum at 2.8

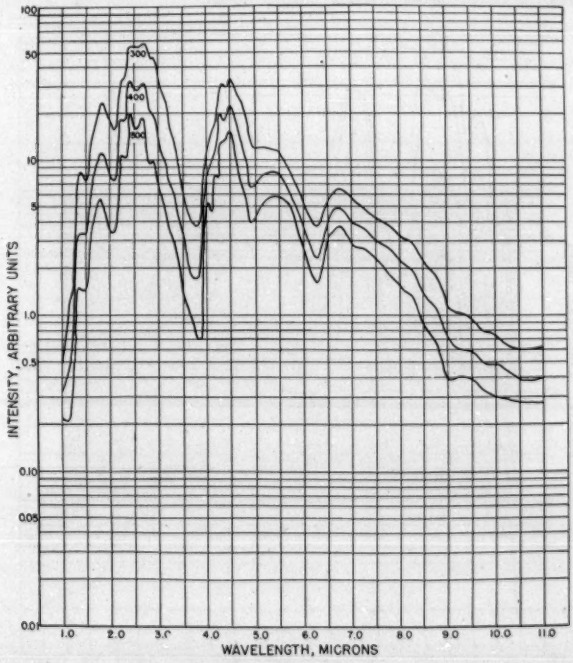

FIG. 4.

microns can be seen at 25 msec. This minimum grows less pronounced up to a time of 200 msec., but becomes slightly more pronounced at later times. The complete time analysis of the spectral distribution could not be satisfactorily reproduced in Figs. 3 and 4. Only those curves corresponding to the times indicated could be presented.

Further work will be carried out, of a more precise nature, with a large-aperture infrared spectrograph, utilizing a bank of ten photothermal detectors. This unit will be capable of determining the spectral intensity, as a function of time, simultaneously at ten different wavelengths. Further experiments will be directed toward a true determination of the temperature as a function of time, the incorporation of a pressure gage to determine pressure as a function of time, the effect of type and exposed area of surface, and other effects.

COMMITTEE ON SCIENCE AND THE ARTS

(Abstract of Proceedings of Stated Meeting held Wednesday, June 8, 1949.)

HALL OF THE COMMITTEE,
PHILADELPHIA, JUNE 8, 1949.

MR. W. LAURENCE LEPAGE in the Chair.

The following reports were presented for final action:

No. 3198: Work of Edgar C. Bain.

This report recommended the award of a John Price Wetherill Medal to Edgar Collins Bain, of Pittsburgh, Pennsylvania, "In recognition of his pioneer investigations into the structure of metallic alloys and particularly for his original work in the application of the isothermal method of studying the rates of transformation of austenite."

No. 3203: Work of William H. Millspaugh.

This report recommended the award of an Edward Longstreth Medal to William Hulse Millspaugh, of Sandusky, Ohio, "In consideration of his outstanding contributions to the art of paper making and to his introduction and promotion of the art of the centrifugal casting of rolls for Fourdrinier machines and other purposes."

No. 3208: Henderson Medal.

This report recommended the award of the George R. Henderson Medal to John Van Buren Duer, of Fairfield, Connecticut, "In consideration of his judgment and guidance in the coordination of engineering matters, including full technical responsibility in the electrification of the Pennsylvania Railroad, and in recognition of his contributions and resourcefulness in research developments in over-all railroad problems."

JOHN FRAZER,
Secretary to Committee.

MEMBERSHIP

ACTIVE MEMBERS ELECTED AT THE MEETING OF THE BOARD OF MANAGERS, JUNE 15, 1949

ACTIVE FAMILY

Donald A. Bunce
Hugh R. Radbill
Richard T. Smith, M.D.
Harold A. Zintel, M.D.

ACTIVE

Philip M. Andress
Russell E. Benner
Henry S. Bourland, M.D.
Edward Brautigam, Jr.
Ralph T. K. Cornwell
Robert J. Donaldson
Raymond M. Fine, M.D.
John M. Foster
Rudolf Friesinger
Harris S. Gerber, M.D.
Reginald N. Gonzalez
Frederic O. Hess
W. Meredith Heyl, M.D.
Stewart Huston
Julian Johnson
Henry J. Karlavage
Paul Karnow
Rudolph M. Lombardi
Hugh B. McCauley, M.D.
Frank T. McGinnis, M.D.
Grace R. Nachod, M.D.
Henry N. Renton
Margaret N. Robins
Henry P. Royster, M.D.
Robert P. Schoenijahn
J. Shepard Smith, M.D.
James B. Taylor

ACTIVE NON-RESIDENT

James C. Cox, Jr.
Edgar D. Sibley

NECROLOGY

Walter I. Cooper '38
Benjamin Rice Faunce '46
George W. Mink, Jr. '42
Edward P. Simon '36
Caroline S. Sinkler '36

NOTES FROM THE BIOCHEMICAL RESEARCH FOUNDATION

Choice of Workers in Research.—ELLICE MCDONALD, Director. No matter how much research is organized, the unit is the worker. Houses are arranged habitations but the unit is the building block. Without careful choice of the unit no research can be successful. After all, it is the men who do the work.

There is no royal road to success in choosing men. Part of it is experience—in life as well as in science, but a good bit of it is a gift, a quality of estimating men and their capacity in a short time and a wise director is one who pays particular attention to the choice of his personnel. The power of organization is great and the effect of a few may be multiplied almost indefinitely and what one individual can accomplish may not be great, but if the units are not carefully chosen, the aggregation into an organization will suffer.

Of course, the choice is limited by the type of research organization. In an industrial research, there must be profits to keep the show going: in some, there are more immediate demands for profits from research than others. Some are so short-sighted as to require research to produce results as required—"Put in the thumb and pull out a plum." This is as unsatisfactory as is the long time research in universities which often continues on and on without a definite aim but goes by continuation and often becomes merely a multiplication of detail.

At one end is technology and at the other is abstract science. One looks upon the other as academic and the other scorns the one as merely practical. The classification of science as organized knowledge is confusing because it suggests an entirely artificial separation between pure science and technology. Civilization began in technology and pure science arose when technology made possible the leisure necessary for its pursuit: but today the applied scientist uses the same strict criteria of accuracy and logical evaluation as does the pure scientist. Actually there are all graduations and no definite division except at one end is the shop laboratory to control the quality of product and at the other end is the cloistered pure scientist remote from the world who may or may not produce a valuable result.

Should all results be valuable? Practical necessity may not be required for scientific advance and many inventions of apparatus devised for scientific advance have been subsequently transferred to practical use. As examples of such invention, Haldane cites the telescope, the cinematograph, barometer, gasometer, galvanometer and cream separator. Most of these have to do with measurement and are really of the nature of scientific aids to extend man's senses and powers

of observation. But after all, most of us are inclined to what Benjamin Franklin called "useful knowledge." Still it is a fallacy to suppose that scientific results come only in response to material needs.

In general, there is some futility in planned research toward a definite end: but there is more futility in research without planning. The great mass of academic research is of that character. This does not mean that the first is technology or applied science and the second pure science or fundamental science so-called. (The purity claimed by some scientists reminds one of Mark Twain's statement, made once with his inimitable drawl, "To the pure, a-all things are i-impure.")

Still in research, as in any other modern phase of effort, it is better to start with a plan and that plan must influence the choice of workers who must carry it out. The field of scientific effort is so great that it takes more than one mind to encompass it. So comes specialization.

When the scope of the research is known and the areas of science well defined, then begins the scrutiny of those who must carry it out. The ideal is the exceptional man but is he to be recognized? The celebrated German chemist, Wilhelm Ostwald, was once asked by a Japanese student of his, "How are you likely to predict what members of a class are likely to distinguish themselves in science?" (It was asked because the Japanese Government sent several hundred young men annually to foreign universities and wanted to get the largest possible return for the financial and human investment.) To clarify his own mind, Ostwald wrote his "Groesse Maenner" in which he examined the great in science, only to reach the conclusion that, not only do we fail to recognize budding geniuses, but that we and our educational institutions do our best to treat them as white crows.

While it is difficult to pick genius in the bud, that is no reason why there should not be some careful screening in the choice of young research workers. The first requirement is that they should want to work. A widow, once in the civil war, brought her son to President Lincoln, looking for a job for him and saying that he wanted to work. Lincoln sent him with a note to Stanton, Secretary of War, "This young man says he wants to work. This is so rare a desire that nothing should be put in its way."

The research worker must be a *worker*. Every student should realize that enduring results are only obtainable through a series of small but continuous daily efforts. Knowledge, whether in science or art or in any human occupation, can only be achieved by daily toil and effort. Time is very vindictive and takes a cruel revenge on everything accomplished without its cooperation. The motto in the library of the Biochemical Research Foundation is "There is no substitute for time."

There must be consideration whereby the man must be driven to act so as to offset Epstean's law that man tends always to satisfy his needs and desires with the least possible exertion. This may be a tendency

in general, but not in particular. But no doubt there must be some compelling impulse. Thomas Alva Edison's wall motto must have been of the nature of a continual spur and reminder to him, "There is no expedient to which a man will not go to avoid the real labor of thinking."

In research, a man must be imbued with the ardor of science. He must have a consuming desire to find out about things and to make them work better. As Willstaetter has said, "Our destiny is not to create but to reveal."

Through many years the question has been asked as to what impels a scientific research worker upon his continued course. Some have answered that insatiable curiosity is the answer; others that man is a born explorer. The spirit of adventure has existed within him since time began. He has ever been trying to extend the frontier, to go over the next hill to see the vision, to find something he did not know and understand.

The adventurous spirit of man (and research is a high adventure) with a burning desire to know things will drive him forward in research now that other frontiers are conquered. His weapons are stronger equipment, new instruments to extend his senses and measurements to a degree not considered possible a short while ago.

Some have said that the research man works for reputation or acclaim. This may undoubtedly enter into it, but it is only a part. The desire for accomplishment and the sense of achievement mean more to the real scientist. An inward feeling of work well done weighs heavier than the gold of the medals. The greater one's accomplishments, the more intensely the smallness of one's ability is realized. It is through this feeling of inadequacy and insignificance that knowledge and achievements can continually progress.

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The real research worker, however his impulse may be described, is driven by an inward force toward an unseen goal and he does not understand this impulse himself. It is more than insatiable curiosity: it is more than the exploration urge: it is best described in the words of Balzac, when speaking of a medical friend and a painter friend, in their desires for discovery and accomplishment. "These passions which are unintelligible to the crowds are perfectly explained by that thirst for the ideal which characterizes creative minds." The creative ideal may influence many types of effort other than research, but it is, without doubt, the compelling impulse in research accomplishment, dimly as it may be seen by those chiefly involved.

The main thing in choice of a research worker is that he wants to work. If he has had some experience in work so much the better, like those who have worked their way through college or have been brought up in a family with the atmosphere of work. But above all, beware of the gifted amateur, the lily-finger boy who plays at research. As Kipling said to a graduating class of Middlesex Hospital Medical School,

"You have been and always will be exposed to the gifted amateur, the gentleman who knows by intuition everything that it has taken you years to learn." To do research, no job should be considered too small or beneath contempt. Dr. William Osler once said to some of his students, "No one can be expected to be a good doctor who is afraid to get his hands in feces."

The real research worker has a different mode of thought from what might be called normal or usual. Many years ago, there was a famous neurologist and psychiatrist, for he was both, named Charcot, who worked at the Salpetriere in Paris. He had three great pupils, Freud, Jung and Janet. The first two returned to their own country and developed systems of psychiatry suitable to their own people. Pierre Janet remained in France and developed with French logic a system based on Charcot's original findings. In general, Janet divided modes of thought into two deviations from the normal or customary.

He called these "hysteric" and "obsessional." The phrase "hysteric" has little to do with hysteria, the disease, and the phrase "obsessional" has little to do with the obsessions of insanity. The hysteric mode of thought is one which is easily influenced and easily diverted, all things to all men, suggestible and going on to the easily hypnotized or the "somnambule." The obsessionist is the one with the fixed idea, resolution in the face of difficulties and even in the face of reason. A typical example of the obsessionist is the Scottish Calvinistic "meenister" who pursues one idea, as did the late President Wilson. It is no wonder that he could not understand Senator Borah who was the diverse type.

Hervey Allen in a recent book has given a good description of an obsessionist with his qualities and the defects of his qualities: "Most people are diffuse or diverse in their interests, fortunately. What in the end attracts permanent attention and fixes a reputation in memory is a man with a single end in view, one which he pursues relentlessly. This lends a precision, and eventually an economy to his actions, in comparison with which the diffuse activities of more normal contemporaries seem trivial and merely time-passing. That a certain insane tenseness frequently accompanies the man of one purpose seems only to cast a more focused and strange light upon his doings. It accentuates him by contrast. And if, as frequently happens, the man with one idea has no fear of consequences in the attainment of his object, a 'hero' is in the making. Such a man can be completely rational about one thing alone. But he can often be superrational about that, and to be superrational is a characteristic of genius."

It may be that the research worker is not so extreme, but the good one is tarred with this brush. He must pursue his aim relentlessly although that aim may be changed with changing conditions, that is, with greater knowledge and vision the result of his own experiments

or those of others. He must think about his work at all times and this will remain in his subconscious mind where prevision and the lead to discoveries are often made.

An example is of August Kekulé whose name should be honored forever for his method of writing down the structural formulae of organic compounds so that anyone with chemical knowledge can see how the atoms of a molecule are linked and can infer many of the properties of the substance. His inspiration gave him foresight or prevision. He had been talking chemistry with a friend and rode home on the top of a bus. "I sank," he said, "into a reverie. The atoms flitted about my eyes. I had seen them in movement, these little beings, but I had never succeeded in interpreting the manner of their movement. That day I saw how two small ones often joined into a pair: how a larger one took hold of two smaller, and a still larger clasped three or even four of the small ones and how all span round in a whirling round dance. I saw how the larger ones formed a row and only at the end of the chain smaller ones trailed along. The cry of the conductor 'Chapham Road' woke me from my reverie, but I occupied part of the night in putting at least sketches of these dream-products on paper. Thus originated the structure theory."

The idea of ring structure of benzene revolutionized organic chemistry and Kekulé, during his residence at Ghent, while he was writing his textbook, describes his prevision. "But it did not go well: my spirit was with other things. I turned in my chair to the fireplace and sank into a half-sleep. Again the atoms flitted before my eyes. Long rows, variously, more closely united: all in movement, wriggling and turning like snakes. And, see, what was that? One of the snakes seized his own tail and the image whirled scornfully before my eyes. As though from a flash of lightning I awoke; this time again I occupied the rest of the night in working out the consequence of this hypothesis.

"Let us learn to dream, gentlemen, then perhaps we will find the truth";—but almost immediately he gave a warning against the publication of dreams until they had been put to the test of waking intelligence and experimentation.

This may seem an extreme case but the Bible says "If there be no vision, the people perish." Still even so matter-of-fact a man as Lord Kelvin has said, "I think about the problem all the time and I gather all the information I can get about it and then, when I am perfectly saturated with the subject and think about it all the time, at some point my mind takes a mortal leap past all the facts." Call this reverie, prevision or what you will, but it is the research imagination which is necessary to everyone in science. More than the daily absorption in the task is required. It requires the projection of one's mind beyond the facts in that intellectual and imaginative realm which is called the research spirit. Occupation and routine are useless alone. Constant

and persistent efforts do not alone suffice, but there must be the divine curiosity to search out new facts in regard to life and the environment in which life exists.

Innumerable trifles collected in an orderly mass although contemptible individually may, by vision and imagination, contribute largely to knowledge. Research requires more than patience, dexterity and exactness, necessary as these are, now since the present criteria are more quantitative than qualitative. An army of excellent but very ordinary people are at present carrying on research into the *minutiae* of unimportance, but these are required to prepare for the exceptional man by whom real advance comes. Where would the world be without such exceptional men as Pasteur, Newton, Franklin, Faraday and other great men whose vision illumines the whole subject so that specialization could take it up and further elaborate it. Advance comes through the exceptional man.

The first condition in an applicant for a research position is that he should be reasonably young. Balzac has said "Integrity and brains in a man under 30 are commodities which can be mortgaged. After that age there is no counting on a man." If he has not begun to find his niche by that time, it will be difficult for him to do it later. In general, research men choose themselves because they seek places where they can follow their innate and overwhelming curiosity with regard to the structure and processes of the world.

Not all men have the research capacity, eager as some of them may be to do this character of work. Desire to do research in a person who is unable to do it is a pathetic thing. The eagerness outstrips the capacity. The accomplishment often fails the desire.

The longevity of the research desire is only to be maintained by a constant struggle against the diffusion of the specialization of its energy. If the struggle is not made, the research desire succumbs after a brief flowering into the common processes of diffused thought. Other people unconsciously fight a man's concentration whenever it diminishes his use to them. Inside of himself, it is fought by the indolence of partial achievement and the incidence of new and extraneous interests which produce a diffusion of energy. Resting upon laurels, enjoying the rewards of partial achievement are fatal to research effort. Motive must overcome the scattering of life's energy into the little parts of less and less usable forms. Once the research desire, the intense curiosity as to the arrangement and order of existing things, is lost, it is rarely recovered. Nothing is more pathetic than the burnt out scientist. The disillusionment of a goal attained should never affect the research worker. There are always new worlds to conquer.

For this reason, the research desire should be sedulously cultivated. The scientist must continue to be prodigiously interested. Research

is strenuous because it involves no routine. Each day is a new opportunity and perhaps a new miracle. For this reason, it is often fatiguing.

My experience in research as such leads me to believe that the lone worker with research ideas has a span of about 3 years in which his ideas are prolific and vital. At the end of that time, it becomes the elaboration of past detail and the continuance of repetition in *minutiae*. Not all fall into this exact category but, in general, I believe this to be true. In our laboratories, immediately a man comes to us we attempt to enlarge his vision and extend his horizon, by interesting him in other phases of work, in other sciences, in other methods of attack upon scientific problems. This prevents the dampening of the stimulation to which the lone worker is subject. This reeducation, so to speak, is not a conscious thing, but the man is caught up into the spirit of the diffusion of knowledge which is present in our laboratory and it is pleasant often to see the flowering of his vision. In research, there is an imaginative impulse and the greatest research worker is he whose intuitions most nearly happen.

The quality which makes a man a real research worker is an independent attribute or in Mendelian parlance a "unit character." This quality is innate or inborn and, if it is not there, no amount of training will supply the lack. Achievement of a high sort is always a combination of several fundamental faculties in no matter what phase of human endeavor. There are differences in degree of attainment and the number with exceptional achievement is small. Take such a phase of human effort as fast-running. It does not require as many fundamentals for outstanding success as hurdling or broad-jumping. The first must be a sprinter, but also must be able to jump; the broad-jumper must sprint to gather momentum and in order to increase that momentum, he must get a forward push into it. These extra faculties are required besides sprinting so that there are greater differences in quality in them than in sprinters where the effort is simpler. So in research which is more complicated as to faculties, because of its very complexity, there are few great. Indeed, the proportion of research workers in general is very small in relation to the total population.

It may be possible some time that research ability may be foreseen and plotted as are certain of the physical characteristics at present. The distribution of many simple characteristics of human capacity follows what is known as the normal probability curve. The wide range over which this normal distribution is found indicates that the law applies to practically all types of inequality, not only for physical characteristics, such as height, weight and head size, but also for mental characteristics as memory, speed and accuracy. Talent of every type and especially of the higher grades is native and cannot be acquired by training or education, but if it is there, it may be developed.

It may seem far-fetched that the normal or probability curve which

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is shaped like a World War II helmet with a hump in the middle and a skewness at each side, should be applied to anything as abstrusely intellectual as research capacity, but if it were possible to measure the fundamental faculties necessary to any type of undertaking, then it would be possible to predict the pattern of distribution, the poor, the the average, the exceptional which would be the marked skewness to the right and so a numerical gradation would be obtained.

What qualities are to be sought for? The desire-to-work motive bulks large: perseverance, resolution, and patience are requisites. Good health is a help to realize the enduring results, obtainable only through a series of small but continuous daily efforts. Knowledge, whether in science, art or in any human occupation, can only be achieved by daily toil and effort.

The amount of previous training and the character of the work the man has done before is important. If there are any publications, these will throw great light, but these should be considered as a background of earlier work, probably immature, and should be judged as to the possibility of improvement in future work.

The applicant's master is of great importance and this implies the atmosphere from which he has come. There have been scientists, all of whose pupils seem to have been imbued with their spirit and to have received part of their capacity. The late Emil Fischer was apparently one of these; every one of his pupils seems to speak of him in the same term, "the great master," and his pupils throughout the world do him credit. The character of the previous work should be weighed. Is he an observationist or an experimenter? Has he been working alone or in a group? And if in a group, what has been his role in it?

Group cooperation and coordination are so important in present-day research that it is well to get some idea of how a new man will function in such a group. For some, it seems impossible to give and take, which is required in group research. Often a new man must be educated in this so that he finds that by taking his part in a group of workers, exchanging his ideas with others, he is not depreciated, but gains from the ideas of others and of other branches of science more then he gives. For some this type of group research consists in having all work on his particular ideas and more or less under his domination. These have no place in the modern scheme of research. There are some who appreciate teamwork only when captain of the team.

After all is said, the director's opinion of a man is the deciding factor in his addition to a research organization. A wise director is careful of the choice of his personnel, for upon that depends its success. The homely old rule still holds—character stands for three-quarters and training for a quarter. Real adjustment and education can be done after induction into the organization and this is always necessary. Inborn capacity counts more, training and environment less.

Good men are those who are stable on the job, are industrious, research productive and are satisfied and happy in their work. However, a potentially good man may turn out poorly if misplaced. If he fails on a job which requires more than his particular abilities, the error is not one of selection but of placement. But it may be taken as a fundamental principle that satisfactory placement presupposes the selection of the proper material.

There are two ways of improving the personnel of an organization: one is getting the best, the other is getting rid of the worst. The desirable qualities are judgment, common sense, modesty, originality and precision, a formidable list and to that must be added an unquenchable curiosity.

BOOK REVIEWS

UNRESTING CELLS, by R. W. Gerard. 439 pages, 14 × 21 cm., drawings and illustrations. New York, Harper and Bros., 1949. Price, $4.00.

This is a re-issue of the first printing which came out in 1940. The author attempts to bring to the intelligent layman some appreciation of the fundamental problems and the basic concepts of certain phases of biology. Since the emphasis throughout is upon the chemical and physical mechanisms governing biological reactions, careful reading is required, particularly in those sections dealing with cell substances and enzymes. This is made as easy as possible for the reader by the excellent organization and the careful selection of the material presented.

With regard to a very few points, the author is on shaky ground. For example, it is doubtful if any living material could traverse interplanetary space without being killed by the radiation that would be encountered. It is even more doubtful that bacteriolytic antibodies act as protein-digesting enzymes, or that the genic material in the chromosomes is protein in nature. Few other criticisms can be raised against the material here presented. Over-simplification of complicated concepts has been avoided and the amount of basic information that is provided is truly astonishing. Suggestions for further reading are not provided, nor is any simple bibliography furnished. The indexing, however, is excellent.

LOUIS DESPAIN SMITH

PATENT LAW, by Chester H. Biesterfeld. Second ed., 267 pages, 15 × 24 cm. New York, John Wiley and Sons, Inc., 1949. Price, $4.00,

For its size, the volume under review is the most comprehensive known to the writer. The conciseness and the novel arrangement or grouping of the subject matter are due, at least in part, to the fact that the author did not deliberately attempt to write a book. The net result is quite salutary.

In most of its chapters, the book deals with various topics of patent law in a substantially standard manner, except for the brevity above noted. In certain other chapters, the author makes exceptionally good presentations of certain other topics. For example:

In Chapter IX the non-patentability of natural products and of "new uses" of old devices is clearly explained and this chapter should be valuable to a practicing lawyer who is always having trouble convincing clients why their pet brain storm cannot be patented.

In Chapter XXI, the necessity of making searches, independently of the Patent Office, and how such searches are made is treated for the first time in any book on patent law known to this reviewer. This too, should be of considerable help to a practicing patent lawyer in convincing clients as to why a search should be made and why searches to be worth making, cost as much as they do.

In its sub-title, the book is said to be intended for "chemists and engineers." This may be true of the more general chapters of the book such as Chapter XIII dealing with the application for patent, Chapter XVII dealing with Licenses (except for the part relating to price fixing which even lawyers find abstruse) and Chapter XVIII dealing with shoprights which, under certain conditions, employers may automatically acquire in the inventions of employees. But, and with all due respect to chemists and engineers, it is felt that the remaining parts of the book, and the book as a whole, belong in the library of a practicing lawyer rather than on the book shelf of a chemist or engineer.

Unlike those who deal in the exact sciences, the author, like all other authors on patent law, attempts to make tangible that which is intangible and to make objective that which is wholly subjective. Reduced to its lowest denominator, the main question is "*What is invention*" and a more subjective concept can hardly be imagined. The veritable plethora of cases deciding this point is, at best, good for the particular facts from which it arose and it is seldom that the facts in any two cases are exactly identical. This is only by way of pointing out difficulties attending a study of this question and not by way of detracting from the merit of chapters II and III which constitute a well documented presentation.

LOUIS NECHO

FIBRE SCIENCE, edited by J. M. Preston. 341 pages, 14 × 22 cm., illustrations. Manchester, The Textile Institute, 1949. Price, 30/.

The art of converting fibers into yarns and yarns into fabrics is as old as human civilization. The high degree of skill, ingenuity and efficiency reached in the textile industry has been attained mostly without assistance from the sciences and scientists. In recent years, more and more scientific research has been done on the structure and behavior of textile fibers, which is one of the principal subjects with which the textile industry is concerned. Modern textile scientists have applied all of the findings of atomic physics, the advances in electrical instrumentation, the knowledge of physical chemistry and all the other scientific tools to unlock the secrets of textiles and the behavior of textile fibers. The present work combines the efforts of fourteen of the leading scientists in this industry, who have written on the subject about which each is the accepted authority.

For the most part, comparatively simple mathematical equations are used and most of the solutions of those problems encountered in the text are given in the form of curves of actual values. Chemical formulas are given frequently in conjunction with their diagrammatic representation together with curves showing their behavior. Many figures and photographs are used to explain clearly what the scientist sees in his laboratory and what the textile engineer or chemist should expect to see in practice.

At the same time, none of the tools of modern science is neglected. Studies made by the use of X-ray diffraction, microscopic examination and chemical analysis are thoroughly explained. Consideration is given to the various theories of fiber structure and a good picture is presented of the chain molecules and their orientation into fibers. The macromolecular structure of both the natural and synthetic fibers is shown to consist of macromolecules of great length relative to their diameter formed from very large assemblies of atoms held together by principal valency bonds. The chemical significance of the cross linkages on the lattice structure is also explained.

After presenting the fundamental concepts of fiber structure in the early chapters of this book, the later chapters discuss the chemistry of various ingredients for synthetic fibers. The characteristics of various fiber-forming polymers are given and the methods of evaluating them are described. Finally, the actual effect of the fiber properties in their relation to dyeing and finishing is described in detail. This work should give textile engineers, chemists and scientists a thorough understanding of the modern trend in fiber science.

FRANK R. SIMPSON

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PRINCIPLES OF MECHANICS, by John L. Synge and Byron A. Griffith. Second ed., 530 pages, 15 × 23 cm., illustrations. New York, McGraw-Hill Book Co., 1949. Price, $5.00.

It is seldom that teachers of mathematics write textbooks which seem to be suited primarily for engineering students. But here in this second edition of a book intended for advanced undergraduate students, the authors, both professors of mathematics, present the principles of mechanics as an orderly, self-contained subject, to be studied and learned as a deductive science. In one respect the field of mechanics can be thought of as being one branch of applied mathematics treating of a combination of physical fact and mathematical know-how.

The main theme of the text is the subject of equilibrium, both static and dynamic. How this equilibrium is established and the mechanics of analysis and computation are somewhat secondary in nature.

The book is divided, somewhat artificially from the physical point of view, into two parts—plane mechanics and mechanics in space—a division which allows the use of simpler mathematics in the plane theory. Part I is devoted to plane statics and dynamics. A first chapter introduces the foundations based upon physical ideas and a logical structure of the science. This is followed by chapters on methods and applications of plane statics and kinematics, methods and applications of plane dynamics and impulsive motion.

While very little of the three dimensional theory was introduced into the first part, Part II is devoted almost wholly to the subject of mechanics in space, with almost complete dependency upon the use of space vectors. One chapter is devoted to products of vectors, vectors

having been introduced early in Part I. Armed with this working knowledge, there are developed results valid for the general force systems encountered in statics in space. The subjects of kinematics, kinetic energy and momentum and methods and applications of dynamics in space, are then considered. Two final chapters devoted to Lagrange's equations and the special theory of relativity conclude the text, except for an appendix devoted to the theory of dimensions.

While this edition is essentially the same as the previous one, several principal revisions were made as concerns the treatments devoted to: the motion of a particle in an electromagnetic field; principal axes of inertia; Foucault's pendulum; the spinning projectile; and the gyro compass.

Transitions between mathematical and physical concepts for specific problems are many and necessary. Each subject considered required its own approach, not only between the mathematical and the physical, but also as to whether the treatment should be based upon fundamental concepts or upon the body of general fact developed up to that point. The result of this open-minded, logical presentation is a book which is extremely understandable and clear in argument.

The typography is well suited. Important passages are italicized, vector equations are written in bold face and the diagrams are clear and unambiguous. Examples are worked out in the text proper, and the many more exercises appearing at the ends of the chapters are sufficient for class room use in a course of one year's duration.

S. CHARP

THEORY OF LIMIT DESIGN, by J. A. Van den Broek. 144 pages, 14 × 22 cm., drawings. New York, John Wiley & Sons, Inc., 1947. Price, $3.50.

Limit Design is not the usual structural engineering book. Most books on the strength of materials present the subject so that the reader assumes everything is exact. The various beam formulas, column formulas, stability formulas and so forth are all based upon assumptions, and, while most authors mention these assumptions, they do not emphasize the dependence of the final results upon them as often as Van den Broek does. Van den Broek writes in a conversational, chatty fashion—sort of lets the audience behind the scene—that may be distracting and even annoying to some readers. He does have a sound argument, and he is constantly justifying it.

Most structures are designed on the bases of the theory of elasticity, and that failure occurs when the material, at some point, yields. Limit design proposes to permit yielding of the material until all, or almost all, the material yields, thereby utilizing more of the material. It uses a ductile stress distribution instead of an elastic stress distribution, an allowable deformation instead of an allowable stress. Most competent engineers realize the limitation of the former basis of design and that all the material may not be utilized. But they also realize that the loads upon which the design is based are not always accurately determinable. Even though most static structures, as bridges and buildings, carry comfortable margins of safety, this extra factor—that the material can yield and yet not rupture —is pleasantly reassuring. Using limit design this extra factor would be eliminated. However, there is no question that Van den Broek has a sound argument and it should be accorded consideration. And, in fact, in some components of airplane structures, this theory, although not known as limit design, has been used.

The *Theory of Limit Design* is a short book. The introductory chapter is the usual one in books on the strength of materials in which such properties of metals as stress, strain, modulus of elasticity, yield stress and ductility are explained. Following are chapters on limit design of simple structures, of redundant beams, of trusses (including columns), connection details, and a short, concluding chapter on the evaluation of limit design. In the chapters on simple structures, beams and trusses, the designs of each by the theory of limit design are compared with the designs by the theory of elasticity. In each case it is shown that by using the theory of limit design, a lighter structure invariably results. In some of our present design practices—as in assuming even distribution of load throughout a rivet pattern under tension—we un-

knowingly apply the theory of limit design. An appendix to the book contains several problems with answers.

As a handbook of design, in the sense that an ordinary strength of materials book contains the solution for many structural problems, the *Theory of Limit Design* is not very useful. But as a statement of the principles of a new approach to structural engineering design, it is an interesting and stimulating book.

E. W. HAMMER, JR.

BOOK NOTES

PRINCIPLES OF STRUCTURAL GEOLOGY, by C. M. Nevin. Fourth ed., 410 pages, 15 × 24 cm., illustrations. New York, John Wiley & Sons, Inc., 1949. Price, $6.00.

In revising this standard text on structural geology, the author has eliminated specific references to source material, as he found that they were little used by the students for whom the book was written. However, material for further study is indicated in the form of selected references at the end of each chapter.

A new section of laboratory exercises has been added with both sample and practice problems. This continues to remain a useful introduction to the deformations of the earth presenting the various ideas and viewpoints.

THE NATURE OF PATENTABLE INVENTION, ITS ATTRIBUTES AND DEFINITIONS, by John E. R. Hayes. Second ed., 187 pages, 15 × 24 cm. Cambridge, Mass., Addison-Wesley Press, Inc., 1948. Price, $5.00.

Rearranged and in part rewritten, this study on invention is made available in a second edition. The discussion of the attributes of invention as a means to a definition of invention is of interest. Many additional cases have been cited in support of the author's thesis.

ROUTE SURVEYING, by George W. Pickels and Carroll C. Wiley. Third ed., 434 pages, 11 × 17 cm., illustrations, tables. New York, John Wiley & Sons, Inc., 1949. Price, $4.75.

This practical book on route surveying, which may serve either as a textbook or a reference book, has been extensively revised to increase its value. Primary emphasis is on railroad surveys, but highway surveys are also treated, with a brief mention of canal and drainage, pipe-line and transmission-line surveys.

Of particular interest to railroad engineers will be the full revision of chapter six on string-lining railroad curves, which presents the basic principles involved as well as detailing the mechanical procedures. Although logarithmic tables have been omitted as of little value, the five-place tables of the natural trigonometric functions have been replaced with seven-place tables and other new tables added.

INTRODUCTION TO PHYSICS, by Harley Howe. Second ed., 599 pages, 15 × 23 cm., illustrations. New York, McGraw-Hill Book Co., Inc., 1948. Price, $4.50.

An elementary college textbook in physics which requires only elementary algebra and plane geometry. It attempts to be "practical" by referring frequently to the everyday experience of the reader. Chapter summaries and numerous problems are among the features of the book.

THE MATHEMATICAL BASIS OF THE ARTS, by Joseph Schillinger. 696 pages, 17 × 24 cm., illustrations, tables. New York, Philosophical Library, 1948. Price, $12.00.

Over a period of twenty-five years Mr. Schillinger did much research on principles of mathematical logic underlying varying forms of art structures. This volume presents his "scientific theory of the arts" in its three main branches: the semantics of esthetic expression, the theory of regularity and coordination, and the technology of art production. He foresees eventually the use of the scientific method in art production and the possibility of having music or painting or poetry designed and executed just as engines or bridges are.

CURRENT TOPICS

Chemical Scrubwoman (*Du Pont Magazine*, Vol. 43, No. 3).—"Tranox" cleaning composition has found many applications, but it was developed as the result of a specific problem. Here is how that came about:

Just prior to D-Day, a large railroad maintenance shop was finding it hard to clean the finished surfaces of passenger cars used by the armed forces. These cars had to be cleaned while in service, and reconditioned and refinished periodically. Because of the time and work involved in removing soilage, schedules were quite often delayed.

The Du Pont Company was asked to assist in the development of some method or product that would speed the clean-up job. As a result, this particular maintenance shop has been using "Tranox" for over two years on cars covered with grime, carbon, rust, oils and grease. It is reported that car surfaces can be cleaned 25 to 50 per cent faster, and that cars are smoother after being cleaned with this agent, making possible a better bonding of new coats of enamel.

Since it is specially designed for heavy-duty work, "brushing" on two or three coats of "Tranox," mixed with water, is enough to take off most soils. However, extra attention may be required in those places where foreign substances tend to collect, such as around window frames, around bolt heads, and on car ends. After the final spot has been touched up and the cleaner has been allowed the required time to work, either warm or cold water from a pressure hose is used for rinsing.

People in the antique business have found the new acidic cleanser good for taking rust off iron grille work, lawn ornaments and old iron hitching posts before refinishing them. The old method of cleaning grilles was to take a steel brush, use plenty of elbow grease and scrub the rust out of the intricate designs. Now antique restorers simply put "Tranox" on with a brush and, after a half hour, rinse it off with a hose. If the amount of rust on the grille is excessive, it may need more than one application. The final result is that the iron is left rust-free and ready to be restored to its original beauty.

Metals cleaned with the new composition will not show "burn marks." Nor does the cleaner leave a film or streak, even though the equipment is washed out of doors and inspected in sunlight.

Indoors, "Tranox" can be used to clean vitreous enamel, acid-resistant porcelain, and glass or lacquered surfaces. It is also utilized in cleaning sanitary equipment because it quickly removes stains and odors. Since "Tranox" is a concentrated paste, the hazard of spilling liquid acid is eliminated.

One note of caution, however—anyone employing the new compound should wear rubber gloves, eye protectors, and, in some cases, special clothing. Since the cleaner contains oxalic acid, it should not be allowed to have porlonged contact with one's skin.

Thirty Miles Up Measured By New Air-Borne Device (*Science News Letter*, May 14, 1949).—Distances above the earth up to 30 miles can be measured with high accuracy by a new instrument, revealed by General Electric engineers. It is a new type of hypsometer, an instrument that measures altitudes by determining the boiling point of a liquid and from it calculating the atmospheric pressure.

The fact that the boiling point of water decreases as the atmospheric pressure decreases is well known. It is also well known that the atmospheric pressure depends largely upon the altitude. This new hypsometer was developed particularly for use in free balloons which are sent high above the earth, reporting automatically by radio the weather conditions encountered. It looks like a radio tube, and was designed to replace the presently used bellows-type devices which expand and contract with changes in the air pressure.

The instrument contains a small vacuum flask which holds about five thimbles-full of liquid. Water is sometimes used, but a liquid with a lower freezing point, such as carbon disulfide, is usually chosen. Inserted in the open end of the liquid chamber is a thermistor, a delicate device for measuring temperature. It is a device in which the electrical resistance changes as the temperature changes.

The steam from the boiling liquid causes the temperature changes. It is the changes in the electrical resistance of the thermistor that are transmitted to the ground station by the balloon's radio. The greater accuracy of this instrument is due to the fact that it is the temperature of the steam itself that is used as an index, not that of the boiling water.

Indestructible Phenoplast (*Science Illustrated*, Vol. 4, No. 6),—On its way from a modern factory in New Jersey is a new chemical product designed to ease the burden of the housewife, boat builder, carpenter or any person who looks at, touches or sits on wood, plaster or metal.

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Called Phenoplast, this chemical is a phenolic resin—an almost indestructible plastic. It is a clear, colorless, liquid finish which, when applied to a surface, works its way so intimately into it and coats the surface so thoroughly that hardly anything can damage it. Applied to a desk or table, it successfully resists demolition from even the metal wheels of a professional roller skater. Used as a glue, it joins two pieces of wood so perfectly that even Charles Atlas, a well-known strong man, cannot separate them.

One of Phenoplast's most important applications today is in boat building. With a Phenoplast coat, a vessel becomes waterproof, sunproof, resists fouling, needs no varnish. A. J. Lockrey, the chemist who developed Phenoplast, claims his product is so waterproof that an ordinary 60-ft. Phenoplast-covered fishing craft can carry two more tons of fish than a non-Phenoplasted boat.

Although plastics exist which do what Phenoplast does, to be effective they must be baked, or pressure-molded into the surface. Phenoplast's secret is a small bottle of catalyst which comes with each can. You simply add the catalyst to Phenoplast before using, spread, wait four hours for it to harden. A second coat must be applied before the coating reaches full effectiveness. Because of its high gloss, a Phenoplast surface can be cleaned with only a damp cloth.

Since it is so new, both Lockrey and Charles Roman, president of the Phenoplast Corporation of New York City, have not yet explored all the possibilities of their new products. One thing they are now investigating is mixing Phenoplast with pigment to create a permanent color coat to walls and furniture. "Permanent" is used advisedly. For, once Phenoplast covers a surface, only hard work and tools can remove it.

Dispersion of Large Cities.—The threat of an atomic war makes it imperative that we break up our large cities into smaller ones as rapidly as we can, Dr. William F. Ogburn, professor of sociology at the University of Chicago, told a class in contemporary trends at the University of Wisconsin recently.

Professor Ogburn has made an intensive study of the problems of dispersing large cities. Since the first atomic bomb was dropped, he has urged that some program of dispersion be adopted.

"There has been a revolution in modern warfare," he said, "a revolution that has brought the destructiveness of war to the civilian population."

The very nature of the atomic bomb makes it particularly effective against large groups of civilians as are found in cities, he continued. At the same time, the cost of the bomb and the problem of delivering it to a target limit its use pretty much to large cities.

"An atomic bomb would probably not be used on a city of less than 50,000 people unless the city were of special military importance, Professor Ogburn said. "The problem, then, is to disperse our large cities in order to protect their civilian population.

"The difficulty with an immediate dispersion is the tremendous cost and resistance to the change that would have to be overcome," he continued. "We at the University of Chicago did some figuring and concluded that rapid dispersion would cost something like 500 billion dollars!"

A more practical approach to the problem, according to the sociologist, is a gradual dispersion over a period of 25 to 150 years. But he emphasized that such a program should begin at once and proceed as rapidly as social and economic conditions permit.

"Even if we avoid war within the next three or four years, it would seem that we will face the danger of war again in 25 or 30 years," Professor Ogburn continued. "By that time Russia will have become highly industrialized and she will certainly seek to readjust her zone of influence."

The plan Professor Ogburn suggested would gradually break up the larger cities into units of 50,000 people or less by locating new industry outside of the cities and by moving old industries as their present plants become obsolete.

Although the trend is for new industries to locate outside the large cities, there is much resistance to dispersion, Professor Ogburn pointed out.

"Those who own real estate resist such a movement because it would mean losing property value," he said. "Big corporations, like a telephone company, resist it because their plants would become obsolete and they would have to build new equipment outside the city. Mayors resist it because it would decrease their cities' income from taxation.

"One of the other groups opposing the plan, curiously enough, is the idealists, who don't want to see any preparation for war, because they want to prevent all wars."

"We in America tend to wait until a war is upon us, then act. But if we are to be prepared for atomic warfare, we must begin at once to speed up the trend toward dispersion."

Air Shipment of Flowers Under Study.—Tests to determine how flowers hold up in air shipment under varying flight conditions have been inaugurated in the laboratories of the Lockheed Aircraft Corporation, Burbank, Calif.,

under the joint auspices of the U. S. Department of Agriculture, the Air Cargo Institute of California, the Southern California Floral Association, and the Lockheed Corporation.

The Floral Association will provide flowers of different varieties of sweet peas, carnations, daisies, stocks, roses, orchids, and gardenias for use in making the tests.

The first of the tests will simulate flight in cargo aircraft, which is unpressurized, unrefrigerated, and not humidified. Other tests are designed to show the effects of shipment in pressurized aircraft where temperature and humidity can also be controlled. The effects of high altitudes will be studied in two of the tests.

B. A. Rose is in charge of the mechanical research for Lockheed which is providing facilities for the test program. W. T. Pentzer and W. R. Barger, storage and shipping specialists of the Bureau of Plant Industry, Soils, and Agricultural Engineering with headquaters at Fresno, Calif., will inspect and judge the flowers to determine any change in color, freshness, firmness, texture, and fragrance and make other records. They will make an official report on their findings.

Directory of Translators.—Solution of a long-felt need in connection with the recurrent problems of locating persons with special language skills for translating scientific and technical articles is forecast in the announcement of the establishment of a Directory of Translators by the Science-Technology Group of Special Libraries Association. The Directory is operated as a free service to bring together clients having translation problems and language specialists competent in various subject fields in science and technology. The Directory has been housed at the Southwestern Research Institute, San Antonio, Texas, under the management of Wayne Kalenich, Librarian.

Individuals or firms needing qualified translators are invited to address inquiries to Mr. Kalenich, and translators are urged to place their qualifications on file with the Directory. Twenty-three different languages are already included among the specialists listed there, and it is hoped soon to expand the Directory to include translators for all fields of knowledge. While no data concerning interpreters has been collected as yet, such information is solicited.

Mr. Kalenich also conducts the Special Libraries Association Translations Pool, which records the existence of technical translations within private files in the U. S., and the conditions of their loan or purchase. This Pool was created in 1945 to prevent or at least reduce unnecessary duplication in the translation of scientific articles. About 3000 translations have already been indexed in the Pool. Persons contemplating the translation of a technical article are urged to make a preliminary check with Mr. Kalenich to be sure that such a translation is not already available.